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Lu, Hongzheng, Ph.D.

The Louisiana State University and Agricultural and Mechanical Col., 1994

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Ann Arbor, MI 48106

MODELING OF
VDT WORKSTATION SYSTEM
RISK FACTORS

A Dissertation

Submitted to the Graduate Faculty of the
Louisiana State University and
Agricultural and Mechanical College
in partial fulfillment of the
requirements for the degree of
Doctor of Philosophy

in

The Interdepartmental Programs in Engineering

by
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ABSTRACT

The objectives of this research were to determine the most important risk factors in VDT workstations associated with physical symptoms and to investigate the interrelationship among these risk factors.

This research consisted of the following four stages:

STAGE 1: Research model development. A conceptual model was developed to describe the interrelationship among the basic components in a VDT workstation system and their possible health effects. A research model was then proposed to describe the hypothesized relationships among the following categories of variables: demographics, task, workstation design, work environment, psychosocial factors, awkward work posture, psychological stress, musculoskeletal symptoms, visual symptoms, and general physical symptoms.

STAGE 2: Methodology development. In order to evaluate the workstation system comprehensively, a method which consisted of a questionnaire, measurement and checklist, and posture analysis was developed. A questionnaire was designed for collecting subjective reports of health symptoms and evaluation of workstation and work environment. A checklist and measurement sheet were designed for collecting data of workstation dimensions, lighting conditions, and anthropometric data. A posture analysis method was also developed for evaluating operators' work postures.

STAGE 3: Field study. A field study was conducted among daily computer users at two different work sites; a local hospital and Louisiana State University. This field

study consisted of three parts; a questionnaire survey, measurements, and the video recording of operators' work posture. Ninety three subjects participated in the study.

STAGE 4: Data analysis. Data was analyzed using both univariate and multivariate approaches. In order to identify the most important variables used for testing the research model development, the relationship between objective and subjective evaluation of workstation and environment were investigated.

Canonical correlation analysis was used to investigate the relationship between each two sets of variables which were described in the research model. Factor analysis was applied to the physical symptoms to help identify the underlying factors. Multiple regression was used to determine the most important factors related to physical symptoms, awkward posture and psychological stress and the interactions among the risk factors. Four factors among physical symptoms were identified and they were named as ocular discomfort, general musculoskeletal symptoms, upper extremity symptoms, and other physical symptoms.

Several conclusions are drawn from this research:

1. The risk factors contributing to the four categories of physical symptoms which are identified from the factor analysis are different and these factors are inter-related. Ocular discomfort is significantly related to screen glare; both general musculoskeletal symptoms and other physical symptoms are related to fatigue; and upper extremity symptoms are related to awkward upper body posture.

2. Psychosocial factors significantly interact with other variables, such as demographic variables, and contribute to awkward work posture and psychological stress.

3. Workstation design significantly affects working posture which in turn contributes to physical symptoms.

4. Interactions exist among the risk factors not only within but also between the seven categories of risk factors.

5. Both subjective and objective measures should be used in investigating risk factors in the VDT system.

The contributions of this research to the investigation of risk factors in VDT systems are as follows:

1. Development of a conceptual model which presents the interaction of basic components in a VDT workstation system.

2. Development of a posture analysis method which can be used to rate the risk associated with the working posture at the VDT workstation system.

3. Development a method which integrated both subjective measures (questionnaire) and objective measures (workstation measurement and posture analysis) for the investigation of risk factors in the VDT workstation system.

4. Classification of the physical symptoms into four (4) categories named; ocular symptoms, general musculoskeletal symptoms, upper body symptoms, and other physical symptoms.

5. Comprehensively examination of the effects of both physical and psychosocial environments and their interactions to physical symptoms, awkward work posture and psychological stress.

The implication of this research is that both the physical and social environment need to be evaluated and the interactions among the components of a VDT workstation system need to be understood in order to determine physical symptom risk factors.

CHAPTER 1

INTRODUCTION

As a result of the rapid development of computer technology, the use of video display terminals (VDTs) has increased dramatically in the workplace. According to a recent OSHA report (OSHA, 1991), there were only 675,000 VDTs in use in the U.S. offices in 1976. After 10 years, in 1986, this number increased to 28 million. At present, there may be anywhere from 40 to 80 million VDTs in the workplace.

Computers have been used in offices and service-oriented establishments for information processing; they are used in factories to control electronic equipment that produce goods; and they are also used by many businesses to maintain control over inventory. Computers are revolutionizing the way business is conducted world wide. Use of computers may increase productivity from 50 to 5000 percent, depending on the nature of the work (Bureau of National Affairs, 1984). Computers are, in some ways, benefiting workers as well as employers. Clerical workers have the opportunity to learn new skills, thereby upgrading their employment status and even improving their earning power. As we enter the 21st century, modern office demands and instant data access needs will increase reliance upon office electronics. The workforce will spend more time on VDT equipment.

Along with this expanding use of VDTs have come reports about adverse health effects on VDT operators. Reports of complaints include musculoskeletal or cumulative trauma disorders (CTDs) and symptoms, vision problems, general physical discomfort, psychological stress, facial skin effects, and reproductive effects (Bonnell, 1987; Bureau of National Affairs, 1984; NIOSH, 1981 and 1992; Pot et al., 1987). Secretaries, data entry clerks and other clerical workers in offices suffer from these health issues more than other professionals (Bureau of National Affairs, 1984).

The reported rates of injury are different in various studies. According to a recent study by National Institute for Occupational Safety and Health (NIOSH), twenty-two percent of U.S. West Communications, workers whose jobs required use of VDT, had potential work-related musculoskeletal disorders and symptoms. LeGrande (1993) surveyed repetitive motion health symptoms and disorders among the directory assistance operators of the Communications Workers of America (CWA). This survey indicated the following symptoms: hand and wrist pain (73%), numbness or tingling of fingers (59%), arm and shoulder pain (78%), neck or back pain (86%), and leg pain (53%). Another survey of 1,307 optometrists shows that about 10 million Americans suffer from VDT-related vision problems (Sunday Advocate, 1993). Complaints about carpal tunnel syndrome, a wrist disorder believed to be caused by the use of computer keyboards have flooded the courts (Occupational Safety & Health Reporter, 1993; The Wall Street Journal, 1993). In most repetitive-stress worker's compensation cases against employers, the awards have been below $50,000 (The Wall Street Journal, 1993). If the injury rate of West Communications workers is extended to all VDT users, the total number of individuals with potential work related musculoskeletal disorders and symptoms will be 17.6 million.

According to the Bureau of Labor Statistics' 1991 survey of job-related injuries and illnesses, 368,000 new cases of occupational illnesses were found among workers in private industry. Out of the 368,000 occupational illnesses, 224,000 were related to repeated trauma injuries, a common problem among keyboard entry workers. This number increased by 21 percent comparing to 185,000 in 1990. The rapid increase of injury rate of cumulative trama disorders has resulted in a proposal for VDT workstation standards by the State of California (CAL/OSHA, 1993) . Concerns about possible health effects of VDT have also prompted numerous public and private studies seeking to determine whether the VDT and its environment do, in fact, adversely affect a worker's health.

Past research has identified many factors associated with VDT operators' health complaints. These factors can be summarized into the following categories: demographics/individual characteristics, VDT tasks, VDT workstations, work environment, psychosocial factors, ergonomics risk factors (repetition, posture, and force), and psychological stress (Bergqvist et al., 1990; Occupational Safety & Health Reporter, 1992). However, these risk factors have not been examined comprehensively. What are the most important risk factors and how these factors affect an operator's physical complaints are not clear.

1.1 OBJECTIVES OF RESEARCH

The objectives of this research were to determine the most important risk factors in VDT workstation system which might affect operator's physical symptoms and to investigate the interrelationship among the risk factors. Specifically, the objectives of this research were:

1. Development of a research model which describes the relationships among the physical symptoms and related risk factors in the VDT workstation system based on past and current research.

2. Development of subjective and objective measures for studying and analyzing the relationship between physical symptoms and related risk factors.

3. Determination of the most important risk factors associated with the physical symptoms.

4. Examination of the interactions between risk factors and their effect on physical symptoms.

CHAPTER 2

BACKGROUND

2.1 VDT TASKS

There are various VDT tasks. According to the predominant mode of interaction with the VDT, VDT tasks can be classified into four categories: data entry, word processing, information retrieval/interactive communication, and programming/computer aided design (CAD).

In data entry work, information that is usually nontextual (numbers, letters, or symbols) is keyed into the computer, often in a repetitive manner according to a set format. The work pace in data entry is often quite high -- 8,000 - 12,000 key stroks/hour is not unusual (Grandjean, 1980) -- and VDT operators may be expected to meet production quotas. Operators may read from printed or handwritten materials or use auditory sources. In many cases the task does not require the operator to look at the screen. Operators in jobs that primarily involve data entry work usually have little or no control over the structure of their work (National Research Council, 1983).

Information retrieval involves calling up information from the computer and reading it from screen. Interactive communication work involves both data entry and information retrieval. In both cases, there are fewer key strokes involved than data entry work and the task is likely to be more screen-intensive. Telephone information operators and airline reservation clerks are examples of workers who seem to work predominantly in this mode.

Word processing involves text entry, text recall, searching test for errors, keying in corrections, and organizing format. The term is often used to refer to secretarial tasks in document preparation, but there are similar operators in such jobs as layout, formatting, proofreading, and editing. Some of the tasks elements are source-document-intensive, some are screen-intensive, and word processing jobs usually involve different combinations of these elements at different times. There is wide variation among these jobs in the degree of control an operator may have over the structure and pace of work (National Research Council, 1983).

Programming and computer-aided design (CAD) often involve programming computers which use VDTs. Many professional jobs -- for example, data analysis, computer programming, scientific research -- include such use of VDTs. In these jobs the VDT may be only one of several tools used, and the amount of time a worker spends at a terminal often varies greatly from day to day. A worker's control over the job tasks is considerable.

Many jobs have elements which contain more than one of these categories, and some jobs many not fit into any of them.

2.2 CHARACTERISTICS OF VDT TASKS

Comparing with traditional office work, the VDT task has the following characteristics: constrained posture and increased load on the visual apparatus (Bruno, 1993; Grandjean, 1984a; Hünting et al., 1981; Grandjean, 1984c). Grandjean (1984a) described the situation of the VDT operator: "movements are restricted, attention is directed to the screen or source documents and the hands are linked to the keyboard."

In VDT work, all the necessary information and instruments required to do the jobs are directly available at the work station resulting in the same seated position being maintained for many hours. Immobility is further increased because of the fixed position of the VDT. Therefore, all the usual lay-out adjustments operators normally do themselves, according to personal preference or changing organizational necessities, are made extremely difficult. The increased load on the visual apparatus among VDT operators is primarily due to the combination of two factors. One is the reduced clarity of the details on the video screen and the other is the limited possibility to use far vision due to physical obstruction, resulting from walls, dividers, windows, blinds etc., used to resolve the most frequent lighting problems. Consequently, the operator is rarely able to use accommodation and convergence/divergence mechanisms to their full extent. Moreover the operator must maintain prolonged near point fixation which is also static because the work entails fixating images and/or objects ("occupational gazes") located between 50 and 100 cm from the eyes (Bruno, 1993; Grandjean, 1984a; Gratton et al., 1990; Jaschinski-Kruza, 1988; Saito, et al., 1993).

After reviewing visual issues, Smith (1987) indicates that VDT use is highly visually demanding and produces visual discomfort.

To summarize, the following characteristics exist in various types of VDT tasks: high concentration, close visual tasks, extended period of sitting/restricted posture, repetitively and/or prolonged use of hands, wrists and fingers. Because of the characteristics of VDT work, Grandjean (1984a) indicated that the VDT operators "are more vulnerable to ergonomics shortcomings, to constrained postures, to unsuitable lighting conditions and to uncomfortable furniture."

2.3 VDT-RELATED HEALTH PROBLEMS

Over the past two decades, workers who use VDTs regularly have voiced concern about their health and about the safety of the terminals. The complaints fall into several distinct categories: musculoskeletal discomfort and strain, eyestrain, and stress. Some operators have expressed fear that VDT radiation emissions may cause cataracts or contribute to birth defects. Most of the health and safety problems associated with the terminals have been reported by clerical office workers.

2.3.1 MUSCULOSKELETAL DISCOMFORT

Musculoskeletal problems among office workers have become the subject of growing concern with the expanding use of video display terminals (Sauter and Schleifer, 1991). The Word Health Organization concluded that "musculoskeletal discomfort was commonplace during work with VDTs" and that "injury from repeated stress... is possible" (World Health Organization, 1987, p1). Lyon (1992) states that cumulative trauma disorders (CTDs) are generally considered the most costly and severe disorders occurring in the VDT workplace.

CTDs is used as a collective term for syndromes characterized by discomfort, impairment, disability, or persistent pain in joints, muscles, tendons, and other soft tissues, with or without physical manifestations (Kroemer, 1992). CTDs may be caused by repeated and/or forceful exertions, often in the hand-arm-shoulder region (Kroemer, 1989 and 1992). The most common and well-known musculoskeletal disorder occurring in the VDT workplace is carpal tunnel syndrome (CTS). CTS is thought to be aggravated/caused by repetitive motion, extension, flexion and twisting of the wrist, which leads to compression on the median nerve passed through the carpal tunnel. Some CTS cases have been reported among computer keyboard workers in U.S. (Occupational Safety & Health Reporter, 1992b). Other hand/wrist-related CTDs associated with VDT use include ulnar and radial nerve compression, tendinitis and forms of tenosynovitis (Lyon, 1992). Apart from wrists, the major sites of discomfort reported by VDT operators are the shoulder and neck areas (Bergqvist, 1984; Hünting et al., 1981; Lu et al. 1993a,.1993b; Sauter et al., 1991). Pain, tenderness and stiffness in the neck (tension neck syndrome) has been shown to be more prevalent among data entry operators than among other office workers. The Japanese authors (Committee on cervicobrachial syndrome of JAIH (1973), Hosokawa (1979)) as well as Läubli et al. (1980) interpret these troubles in the upper extremities as a functional and organic disease of the locomotor system and call it the 'occupational cervicobrachial' syndrome.

According to a recent study by National Institute for Occupational Safety and Health (NIOSH), twenty-two percent of U.S. West Communications workers whose jobs required use of VDT had potential work-related musculoskeletal disorders and symptoms. This study reported that 15 percent of the 533 total participants had tendon-related upper extremity disorders; 8 percent had muscle-related upper extremity disorders; 4 percent had nerve entrapment syndrome; 3 percent had ganglion cysts; and 3 percent had joint-related disorders. The hand/wrist area was the body part affected in 12 percent of the study's subjects; neck area in 9 percent; elbow area in 7 percent; and shoulder area in 6 percent (NIOSH, 1992). LeGrande (1993) also reported catastrophic occurrences of repetitive motion health symptoms and disorders among the directory assistance operators of the Communications Workers of America (CWA). The 1992 survey indicated the following symptoms: hand and wrist pain (73%), numbness or tingling of fingers (59%), arm and shoulder pain (78%), neck or back pain (86%), and leg pain (53%).

Sauter et al. (1991) reported high prevalence rates of musculoskeletal discomfort among 539 data entry VDT users. Almost constant discomfort was most common for the low back (33% of respondents), followed by neck and buttocks discomfort, each reported at the almost constant level by 27% of respondents. Almost constant right shoulder discomfort was reported by 15% of respondents. The findings suggest the need for greater attention to relief of stress to the neck, shoulder girdle, and wrist in VDT work.

2.3.2 VISION PROBLEMS

VDT-users have a high incidence of eye discomfort. Reported incidence from field studies vary, levels between 40-92% (at least occasional) to 10-40% (daily) have been reported (World Health Organization, 1987). The most common vision-related complaint reported by VDT operators is that of fatigue -- tired, aching eyes and "heavy" eyelids. Other frequently voiced complaints are of irritation (burning, itching, watery eyes), blurred vision, and difficulty in focusing. Some workers also complain that their perception of color is altered after prolonged VDT use (Bureau of National Affairs, 1984; NIOSH, 1981).

Vision complaints were classified as ocular or visual symptoms. Ocular symptoms were defined as any incident of ocular discomfort such as tired eyes, dry eyes, tearing/itching eyes, burning eyes, sore eyes, and red eyes. Visual symptoms were defined as any incident of impaired vision such as blurred vision and double vision (Bruno, 1993; Collins, et al., 1990; Howarth and Istance, 1986; Läubli, et al., 1981; Schleifer, et al., 1990). Duke-Elder and Abrams (1970) classify the eye symptoms as visual (especially blurring), ocular(the eyes feel tired, hot, uncomfortable, or painful), referral(e.g. headaches), and functional (behavioral). Some other researchers just use the term visual fatigue or asthenopic as a reference to any subjective visual symptom or distress resulting from use of one's eyes (National Research Council, 1983; Rubino et al., 1993; Tyrrell and Leibowitz, 1990; Watten et al., 1992).

The visual discomfort experienced by VDT operators tends to persist longer than that experienced by other office workers. Läubli et al. (1981) interviewed both VDT operators and traditional office workers and found that in the data-entry terminal group the incidence of visual impairments apparent the next morning was still noticeable; however, it was nearly zero in traditional office work. Some health professionals and ergonomists have raised the possibility that more serious, permanent eye damage may result from prolonged VDT use. Considerable debate has been focused at the question of pathological changes of the eyes. Acquired myopia has also figured in recent discussions.

2.3.3 PSYCHOLOGICAL STRESS

Stress is another major health problem among VDT operators, particularly among those performing clerical tasks. A 1977 NIOSH study (cited by Bureau of National Affairs, 1984) reported that office workers (secretaries, office managers, and managerial administrators) were among the 12 (out of 130) occupations associated with the highest levels of stress-related disease. This study shows that secretaries had the second highest incidence of stress-related diseases. The stress generally experienced by clerical office workers due to boredom and lack of autonomy tends to be exacerbated by VDT work. According to a 1981 NIOSH study (NIOSH, 1981), anxiety, irritability, sleep disorders, and fatigue -- classic symptoms of job stress -- are prevalent among VDT clerical workers. These conditions represent only the immediate effects of job stress; the long-term effects remain unknown.

2.3.4 OTHER HEALTH COMPLAINTS

Some general physical symptoms, such headaches, stomach pain, and ringing or buzzing in ears, are also found in VDT operators. In NIOSH 1979 survey, ringing or buzzing ears and stomach pain among VDT operators are higher than non-VDT operators in all three sites surveyed (NIOSH, 1981).

In addition to the above symptoms, skin symptoms related to VDT work have been reported since the late seventies, mainly from Scandinavian countries (Stenberg, 1993). However, many explanations for skin symptoms appearing in VDT workers have been offered without any consensus being reached. Physical as well as psychological and social factors have been suggested but many investigators even question the very existence of skin problems related to VDT work (Stenberg, 1993).

Another health issue among VDT workers is regarding the possibility that a woman's work with a VDT during her pregnancy may influence the outcome of her pregnancy. This concern did originated with the published descriptions of "clusters of unfavorable pregnancy outcomes," i.e., the occurrence of several miscarriages within an identifiable group of pregnant women working with VDTs. However, the epidemiological studies that have been performed have not been able to demonstrate an association between work with a VDT during pregnancy and increased risks of miscarriage, giving birth to a malformed child, or growth retardation of the fetus (Bergqvist and Knave, 1993).

2.3.5 SUMMARY

In summary, VDT work is a close visual task involving frequent eye movement, high concentration, repetitive hand motion and static sitting posture. Past studies have show high prevalence rates of complaints of musculoskeletal discomfort, visual discomfort and stress. These reported complaints may be related to VDT use and/or the work environment.

CHAPTER 3

LITERATURE REVIEW

Concerns about possible health effects of video display terminals have prompted numerous public and private studies seeking to determine whether the VDT and its environment do, in fact, adversely affect the worker's health.

3.1 RISK FACTORS

Many factors have been identified which may affect VDT operator performance and physical symptoms. These factors can be summarized into the following categories: demographics/personal characteristics, VDT exposure/task demands, computer system and equipment design, workstation design, work environment, psychosocial factors, work posture, and psychological stress.

3.1.1 DEMOGRAPHICS

Individual factors such as age, sex, eye quality and work habit may have certain effect on the worker's performance and health (Asakura and Fujigaki, 1993; Bergqvist et al.,1990; NIOSH, 1992; Pot et al., 1987; Sauter, 1984; Sjögren & Elfström, 1990).

Asakura and Fujigake (1993) found that the impact of office computerization on the perceived job characteristics (psychosocial factors) differs by gender; males appeared to be influenced greater than females. Lim and Carayon (1993) found that gender was significantly related to upper extremity cumulative trauma disorders (UECTD); women reported higher UECTD than men.

Sauter (1984) found that age and marital status were related to the strain measure (job dissatisfaction, mood disturbance and illness symptoms) and contributed

10-30% of the explained variance in these strain measures. The fact that increasing age predicts reduced strain, is said to attributed to survival ("healthy worker") effect.

Pot et al. (1987) found that eye fatigue appeared to be related to eye quality. Sjögren and Elfström (1990) found that VDT users with lower visual acuity reported more eye discomfort than those with higher visual acuity. However, this was valid only in the younger age-group. In the older group, the age factor seemed to be more important than low visual acuity. Sauter found significant effect of the need for corrective eyewear in the prediction of eye complaints after adjusting for age. Consistent with observations by other researchers (Cakir et al., 1978; Läubli et al., 1981), VDT-users with corrective eyewear reported greater eye strain that those without. The effect was restricted mainly to users of monofocal lenses. These effects were much less evident in the control group (non-VDT users) (Sauter, 1984). Schleifer et al. (1990) reported an interaction between age and eyewear in the prediction of ocular discomfort. Older workers (i.e., age≥40) with glasses reported much less discomfort than did older workers without glasses. However, Läubli et al. (1981) concluded that work at VDTs may cause impairments in operators both with and without eye defects. A recent NIOSH study also found that factors associated with upper extremity disorders included demographics and prior medical conditions (NIOSH, 1992).

However, some studies found weak or no relationship between demographic data and musculoskeletal discomfort. Sauter and Schleifer (1991) investigated musculoskeletal discomfort and related factors among 539 data entry VDT users. The regression analyses, which is aimed at examining the effects of demographics (i.e., age, height, weight, mass and glasses) and VDT exposure variables (i.e., VDT hours and tenure) on each musculoskeletal discomfort measure demonstrates that all of the demographic and VDT exposure variables, except weight and glasses, have an effect on at least one of the discomfort measures. However, none of the demographic or VDT exposure variables contributed an increment of at least five percent of the explained variance in the discomfort measures. They concluded, that none of the demographic and VDT exposure variables can be used for the prediction of musculoskeletal discomfort measures. Lim and Carayon (1993) found no significant relationship between demographics variables, i.e., age, gender, tenure with employer, job position, or fatigue, a psychological measurement. Other studies also found that only a few demographic variables were related to a few worker strain variables (Carayon, 1992; Yang and Carayon, 1993). Therefore, these studies had presented their results without controlling for demographic variables, for sake of simplicity (Carayon, 1992; Yang and Carayon, 1993).

3.1.2 VDT TASK FACTORS

The task factors include the VDT exposure variables (VDT use vs. non-VDT use and the cumulative hours spent working with VDT daily) and type of VDT tasks. Many studies have found a direct relationship between task factors and health complaints (Gunnarson and Söderberg, 1983; Läubli and Grandjean, 1984; Pot et al., 1987; Rubino et al., 1993). Some studies found indirect relationships (Asakura and Fujigaki, 1993), while other studies showed weak or no relationships (De Groot and Kamphuism, 1983).

In two NIOSH-supported field studies cited by Pulat (1992), Smith et al. (1982 and 1984) reported more health problems (irritability, stomach ache, nervousness) among clerical VDT operators as compared to control groups (no VDT exposure) and suggested the adverse effect of VDTs. In a longitudinal study by Bergqvist *et al.*(1990), the risk of acquiring eye discomforts has been shown to be related to VDT work. Watten et al. (1992) also reported that prolonged VDT work (2 and 4 hours) leads to a significant reduction in visual acuity and contrast sensitivity. Further, increased complaints about asthenopic, musculoskeletal (neck, shoulder and/or upper arm, upper back and/or low back), and other symptoms, i.e., general tiredness and concentration problems, were reported.

Läubli and Grandjean (1984) plotted the incidence of "eye strain" and the range or mean of the daily time spent on VDTs from the data of 12 field studies. The plot shows a linear relationship between the incidence of eye strain and the daily working time at VDTs. This relation could just as well be caused by a relation between length of VDT-use and the uniformity of work (Läubli and Grandjean (1984). Gunnarson and Söderberg (1983) found that an increase in the time that was spent on VDTs during the unchanged total working time caused an increase of eye-fatigue. This conclusion is further supported by another study conducted by Rubino et al. (1993) where they found that asthenopia (eye burning, eye heaviness, headache, and tearing) is possibly related time hours spent at the VDT. The increased musculoskeletal discomfort during VDT work has also been found to be a function of work hours (Bergqvist, 1984; Hagber and Sundelin, 1986).

Sauter (1984) found cumulative time of VDT use predicts none of the strain measures (job satisfaction, mood disturbance, and illness symptoms). Duration was predictive of musculoskeletal complaints in only one area (upper torso) and the effect is marginal (p=0.046). But Sauter found that VDT use versus non-VDT use is influential in predicting mood disturbance (VDT-use is actually associated with improved moods). Of particular interest, VDT use/non-use interacted significantly with job demands in the prediction of all three strain measures. Rising job demands were associated with increased mood disturbance for VDT-users, but not for non-users. Khaleque (1993) conducted a study among bank employees and found that non-VDT users experienced significantly greater degree of job stress and perceived fatigue than VDT users.

Asakura and Fujigaki (1993) found that the effect of VDT exposure on the worker's health is indirect, mediated by the job characteristics (psychosocial factors).

Some studies found no significant relation among VDT exposure and visual complaints and visual parameter changes. De Groot and Kamphuis (1983) conducted a study on the same group of VDT users just before, just after, and two years after the introduction of VDTs and found that the number, type, and severity of complaints did not change over time. The optometric measures (e.g., visual acuity, accommodations, and critical flicker fusion) showed no deterioration other than aging effects.

Different types of VDT tasks may have an effect on the health complaints. Rubino et al. (1993) conducted a longitudinal survey of ocular disorders and general complaints among 17,821 VDT operators in the Italian Telecommunication Company and found that the most stressing VDT task seems to be that of directory assistance operators, whose rhythm of work is paced by a continuous performance system using electronic monitoring. Then comes the job of dialogue and then data entry operators, whose tasks require adaptive effort due to their repetitiveness. Discomfort was reported to be much less for word processor users (Rubino et al. 1993).

3.1.3 WORKSTATION DESIGN

Workstation factors, including screen characteristics, height and position of screen, height and position of keyboard, adjustability and comfort of seat, seat height, table height, viewing distance, and lack of a manuscript holder have shown to be related to eye symptoms and musculoskeletal symptoms (Bergqvist et al.,1990; Collins et al.,1990; Hünting et al., 1981; Pot et al. 1987; Rubino, 1990; Stewart, 1980; Wilkins, 1991). The constraints imposed by the workstation furniture prevent the optimal adjustment of CRT, keyboard, and source material (Bergqvist et al.,1990; Stewart, 1980). The effect of workstation design on the musculoskeletal complaints is generally accepted to be mediated by the constrained posture (Grandjean et al., 1984; Hünting et al. 1980; Hünting et al., 1981; Life and Pheasant, 1984; Maeda et al., 1980; Mandal, 1987; Zacharkow, 1988).

Stammerjohn et al. (1981) have noted an association between reports of visual discomfort and screen characteristics including screen height, angle, glare and flicker. Collins et al. (1990) found that screen legibility significantly influences the occurrence of symptoms of ocular discomfort and showed a positive but not significant association with visual (blur) symptoms. Pot et al. (1987) reported that blurred VDT characters is related to eye complaints. Turner (1982) also reports that asthenopia (eyestrain) amongst VDT users may be caused by poor screen legibility and poor screen stability. Smith (1987) indicates that poor screen images is one of the cause of visual discomfort. Aspects of screen legibility such as dot matrix design, font style, character luminance and visual angle of the characters have all been shown to affect work performance measures (Brown et al, 1982; Snyder and Taylor, 1979).

Miyao et al. (1988) studied the effect of screen resolution on eye fatigue and readability. It was concluded that a high resolution screen is important for readability when undersized characters are used. However, the author did not make any conclusion about the effect of screen resolution on eye fatigue.

Wilkins (1991) indicates that the way in which text is laid out is critical for providing unambiguous information, reduced computational complexity for the visual system and discomfort. Certain geometric patterns can be uncomfortable to look at, such as stripes (Wilkins et al., 1984).

The thickness of keyboard has effect on the musculoskeletal complaints. Hünting et al. (1980) found significant correlation between complaints and the height of the keyboard surface from the table: that in data-entry terminals and conversational terminals which were higher than the median values of 7-8 cm, more pain in the hands and arms were reported. Pot et al. (1987) observed that thick keyboards are related to awkward work posture.

Table height and keyboard height are significantly related to the frequency of musculoskeletal complaints (Grandjean and Hünting, 1977; Hünting et al., 1980; Hünting et al., 1981). Hünting et al., (1981) found that the lower the table and keyboards heights above the floor, the more frequently pains in shoulder, neck and arms were indicated. This relationship is clarified by the observations at workplaces: the higher the table, the closer the documents were to eyes, then the better is the posture of head and trunk, and the fewer are the complaints since the documents were placed flat on the table at all workplaces. Other surveys of office workers (Grandjean and Hünting, 1977; and Hünting et al., 1980) have found relationships between excessively high keyboard positions and reported discomfort in the neck and shoulders. Pot et al. (1987) found that instability of the chair and lack of space for legs are associated with musculoskeletal complaints.

The height of screen has an effect on operator's typing performance and perceived musculoskeletal discomfort. This study conducted by Lu and Aghazadeh showed that placing the screen at eye level results in fewer complaints of the discomfort in the neck, shoulder and upper back.

Viewing distance is an important factor that determines the load on accommodation and convergence of the eyes. The shorter the distance at which the eyes fixate, the greater becomes the force exerted by the ciliary muscle (Fisher, 1977). Thus, the closer the visual object the greater becomes the strain of fusion. It is generally accepted that excessive tension of the ciliary and extraocular muscles produces visual strain and that, as a consequence, visual strain increases as the viewing distance shortens (Jaschinski-Kruza, 1988). Jaschinski-Kruza (1988) conducted a laboratory experiment to examine the viewing distance (i.e. 50cm and 100cm) to VDT and visual strain. The result shows that subjective reported visual strain was higher in the 50cm condition comparing with 100cm condition.

Workstation variables are related to working postures. Pot et al., (1987) indicated that absence of manuscript holders and difficult or absent height-adjustability of VDT's and keyboards, in combination with lack of footrests and thick keyboards are related to awkward work posture. Wall et al. (1992) found that placing the VDT monitor at eye height (middle of the screen) would improve an operator's sitting posture. A field study conducted by Coniglio and Paci (1987) among software design workstations shows that the heaviest restrictions imposed by the hardware (height, width, and depth of the table, and height and design of the chair) refer to the eye-screen distance, head movement and curvature of the trunk.

Zacharkow (1988) and Maeda (1977) indicated that the key to reducing the potential for musculoskeletal stress at VDTs and other office machines is a well-designed, adjustable workstation that will provide proper body stabilization for the specific tasks being performed. Several studies have already demonstrated a reduction in musculoskeletal complaints or stress, along with an increase in productivity, as a result of properly designed workstations (Dainoff, 1983, 1984b; Grandjean, et al. 1984; Ong, 1984; Pustinger et al., 1985; Secrest and Dainoff, 1984;). A field study by Grandjean et al. (1984) shows that after the adjustment of the workstation to the preferred settings and using the chair with high backrest, the majority of the operators rated their body postures as relaxed, and the musculoskeletal complaints were reduced significantly.

3.1.4 WORK ENVIRONMENT

Poor ambient light level has been found to be a cause of eye-strain (Bergqvist et al.,1990; Sauter, 1984; Stewart, 1980; Wilkins, 1991). The variables in the evaluation of lighting condition are illuminance at screen, keyboard, document, and work surface; screen background luminance; keyboard luminance, screen-background luminance ratio, screen reflectance, average background luminance; presence of a luminaire and/or window in the visual field; brightness of the luminaire or window; and visual angle to the luminaire or window (Sauter, 1984; Schleifer et al., 1990).

Sauter (1984) found that eye-strain is significantly associated with illumination at keyboard and worksurface. However, display related variables (luminance, screen-background luminance ratio, reflectance, and glare) are not directly related to eye-strain, but they tend to be related to ambient lighting indicators.

Schleifer et al. (1990) found that eye discomfort increases for VDT users with a window in the visual foreground. They also found an interaction between the illumination at the keyboard and the illumination at display. The interactive effect suggests that when keyboard illumination is low (possibly indicating insufficient workstation illumination), increasing illumination at the display might be associated with improved lighting for visual tasks and, hence, reduced discomfort. On the other hand, increasing screen illumination at other than low levels of keyboard illumination may create the potential for discomfort or disability glare and, thus, visual discomfort. However, the model is generated under a relaxed stepping criteria (i.e., relaxed significance level).

High contrast between the screen and the surrounding area, especially between the screen and the source document, cause long lasting eye fatigue. Läubli et al. (1981) found that incidence of eye impairments at the end of work was increased amongst the high contrast group and continued during leisure time and even until next morning. However, in typists and traditional office work there was no significant relation between contrast and eye fatigue. Among users of data-entry terminals, impairments were increased in the group with a high contrast between source documents and the table.

3.1.5 PSYCHOSOCIAL FACTORS

Psychosocial factors are recognized to be critical in both the causation and the prevention of disease and in the promotion of health (Kalimo, 1987). Psychosocial factors are "pertaining to or concerning the mental factors or activities which determine the social relations of an individual" (Webster's New Twentieth Century Dictionary of English Language, p.1451). Some indicators of psychosocial factors are: work pressure, quantitative workload, work pace, job control, utilization of skills, task clarity, social support from supervisor, colleague support, and job future ambiguity (Carayon, 1992; Mclaney, 1988; Rogers, et al., 1990; Sauter et al., 1989; Staifort, 1990; Stellman et al., 1987).

A NIOSH study found that the work practices, psychosocial aspects of the workplace, and electronic performance monitoring contribute to upper extremity disorders and symptoms (NIOSH, 1992). This result is supported by other research (Bergqvist et al.,1990; Lim and Carayon, 1993; Sauter, et al., 1992; Smith et al., 1992). A group of NIOSH researchers conducted a field study of newspaper and telecommunication workers to examine job risk factors for upper extremity musculoskeletal disorders and concluded that job factors such as heavy work pressure and surges in workload, lack of job security, lack of social support and amount of VDT work were predictors of upper extremity symptoms and disorders (Sauter et al. 1992).

Psychosocial factors are significant predictors of psychological stress outcomes (i.e. tension, anxiety, depression and fatigue) (Järvenpää et al., 1993; Miezio, et al., 1987; Rogers et al., 1990). Lim and Carayon (1993) found that the effect of psychosocial factors is indirectly related to the upper extremity cumulative trauma disorders through psychological stress and ergonomic risk factors (i.e., repetition and posture). Carayon et al., (1993) found that task control is related to decreased levels of several job stressors which, in turn, are related to several measures of worker stress (mood disturbances, anxiety, and distress).

Pot et al., (1987) found an interactive relation between health complaints on the one hand and the percentage of working with VDT, work pressure (time pressure, mentally strenuous work, etc.), and work atmosphere (promotion possibilities, pay, etc.) experienced on the other hand. It was concluded that headache, eye fatigue, musculoskeletal complaints and complaints of general fatigue and nervousness are related to a combination of VDT exposure, substantial work pressure, and a poor work atmosphere (Pot et al., 1987).

3.1.6 PSYCHOLOGICAL STRESS

Psychological disorders in the workplace have been identified as being among the 10 leading work-related diseases and injuries (NIOSH, 1988). NIOSH (1988) recommended that "specific attention should be given to the increasing body of evidence linking physical illness and psychological factors (p.3). Psychological stress measures are usually boredom, fatigue, tension-anxiety, distress, anger, and depression (Carayon, 1992; McNair et al., 1971; Rogers et al., 1990; Sainfort, 1990). Psychological stress is found to be a mediator of the effect of psychosocial factors on musculoskeletal discomfort and disorders (Lim and Carayon, 1993). However, no further literature can be found to link psychological stress and musculoskeletal discomfort and visual fatigue.

3.1.7 AWKWARD WORKING POSTURE

It has been recognized that poor working posture (awkward posture) is a potential risk factor for musculoskeletal problems in VDT work (Boussenna et al., 1982; Grandjean, 1987; Life and Pheasant, 1984; Lim and Carayon, 1993; World Health Organization, 1987; Zacharkow, 1988).

Life and Pheasant (1984) indicated that the stressful posture may cause physical fatigue and/or discomfort. A stressful posture is defined here as that is maintained by sustained active tension of the musculature and/or by passive loading (compression or tension) of tissue. The requirement to maintain such postures for long periods is considered undesirable, because static muscular tension can only be maintained with the occurrence of certain physiological and psychological costs: the use of energy and the production of waste products, which, in turn give rise to fatigue and discomfort. The effects will occur more quickly under static conditions, as a consequence of ischaemia (a reduction in the blood supply to the muscles caused by their own contraction). The compression of tissue for long periods can also lead to acute or chronic symptoms or discomfort or disability (Life and Pheasant, 1984).

Working posture is determined by the interaction of many factors in the work place. Features of workstation layout (e.g. the height, orientation, and location of the VDT, keyboard, and supporting surface) determine how a worker must position his/her body when performing a task. Visual demands interact with workstation to determine the posture of the neck and trunk. The anthropometric characteristics of a worker interact with all of the above factors to determine the specific postures used to perform a job (Life and Pheasant, 1984; Pot et al. 1987).

Life and Pheasant (1984) found from an experiment that increasing keyboard height and placing the source document flat on the table would result in stressful shoulder and arm postures and increase discomfort. Other studies have found that one result of poor ergonomic placement of the screen and source documents is an excessive forward inclination of the head, which is associated with an increase in musculoskeletal complaints from the operator (Hünting et al., 1981; Maeda et al., 1982; Sauter et al., 1983).

An increased forward tilt of the head will result in an increased static loading of the posterior neck muscles, as well as an increase in the cervical spine compression forces (Chaffin, 1973; Less and Eickelberg, 1976). An increase in forward inclination of the head is associated with musculoskeletal complaints involving the posterior neck, shoulders, and upper back (Hünting et al., 1981; Maeda et al., 1982; Grandjean et al., 1982); it is a major cause of headache with VDT and other office machine operators

(Robinson, 1980; Stewart, 1979; Travell, 1967); It can also increase the stress on the lower back (Grandjean et al., 1982).

Collins et al.(1990) found that vertical head movements significantly affected the incidence of postural/headache symptoms. The greater the amount and frequency of vertical head deviation when performing tasks at the VDT, the lower the incidence of postural/headache symptoms. However, Lim and Carayon (1993) found that repetitive movement and dynamic posture are associated with more complaints of musculoskeletal symptoms.

3.1.8 INTERACTIONS OF RISK FACTORS

Besides the direct and indirect effect of the risk factor on the health complaints (musculoskeletal discomfort and visual complaints), some studies have found the effect of the interaction of the risk factors within the same category of variables, such as the age and eye quality (Sjögren and Elfström, 1990), VDT use and job demands (Sauter, 1984), illumination at keyboard and display (Schleifer et al., 1990). However, only one study has examined the interaction of the risk factors in different categories.

Pot et al. (1987) found a significant interactive relationship among health complaints on the one hand and the percentage of time of working with VDT, work pressure (time pressure, mentally strenuous work, etc.), and work atmosphere (promotion possibilities, pay, etc.) experienced on the other hand. However, the relationship is week.

3.1.9 SUMMARY

The possible risk factors for the health complaints in the VDT workplace are listed in Table 3.1 and Table 3.2. Table 3.1 lists the summary of risk factors and their net effects which have been discussed above. Table 3.2 summaries the possible causal relationships according to the stress and strain outcomes.

Table 3.1. Summary of possible risk factors and their effects

Possible Risk Factors	Net Effects*	Authors
Demographics		
- Age	Strain (job satisfactory, mood disturbance, illness symptoms) (-)	Sauter (1984)
- Sex (1:male, 2:female)	Perceived job characteristics (-) Upper extremity symptoms (+)	Asakura and Fujigake (1993) Lim and Carayon (1993)
- Low eye quality (or wearing glasses)	Visual symptoms (+)	Cakir et al. (1978) Läubli et al. (1981) Lu et al. (1993b) Pot et al. (1987) Sauter (1984)
- Type of eye wear (bifocals)	Headaches and postural discomfort (+)	Collins et al. (1990)
- Age x eye quality	Visual symptoms	Sjögren and Elfström (1990)
- Prior medical conditions	Upper extremity disorders	NIOSH (1992)

(table con'd.)

*NET EFFECT OF THE POSSIBLE RISK FACTORS:
(+) Positive effect. Higher level of risk factor is related to more symptoms;
(-) Negative effect. High level of risk factor is related to less symptoms.

(Table 3.1 con'd.)

Possible Risk Factors	Net Effects*	Authors
Task		
- VDT use v. non-VDT use	General health problems (+) (irritability, stomach ache, nervousness) Visual symptoms (+) Musculoskeletal symptoms (+) Mood disturbance (-) Job stress and fatigue (-)	Bergqvist et al., (1990) Khaleque (1993) Läbli et al., (1981) Sauter (1984) Smith et al. , (1982) Smith et al., (1984)
- Hours spent at VDT work (amount of VDT work)	Visual symptoms (+) Visual acuity (-) Contrast sensitivity (-) Musculoskeletal symptoms (+) General tiredness (+) Concentration problems (+)	Bergovist (1984) Gunnarson and Söderberg (1983) Hagberg and Sundelin (1986) Läubli and Grandjean (1984) Lu et al. (1993b) Rubino et al., (1993) Sauter et al., (1992) Watten et al., (1992)
- Rest pauses	Perceived discomfort (-) Static load on the right upper trapezius muscle (-)	Hagberg and Sundelin (1986)
- Type of VDT tasks (word processing, data entry, dialogue, directory assistance)	Visual symptoms (+) General complaints (+)	Rubino et al. (1993)
- VDT use vs. non-VDT use x job demands	Mood disturbance (+)	Sauter (1984)

(Table con'd.)

*NET EFFECT OF THE POSSIBLE RISK FACTORS:
(+) Positive effect. Higher level of risk factor is related to more symptoms;
(-) Negative effect. High level of risk factor is related to less symptoms.

(Table con'd.)

Possible Risk Factors	Net Effects*	Authors
Workstation design		
- Screen legibility	Eye discomfort (-)	Collins et al. (1990)
	Performance measures (+)	Brown et al. (1982)
		Pot et al. (1987)
		Snyder and Taylor (1979)
		Turner (1982)
- Close view distance (< 100 cm)	Visual fatigue (+)	Jaschinski-Kruza (1988)
		Tyrrell and Leibowitz (1990)
- Screen: Height	Working posture	Lu and Aghazadeh (1993)
Lack of height adjustability	Musculoskeletal symptoms	Pot et al. (1987)
	Typing performance	Wall et al. (1992)
- Keyboard: Thickness		
Height	Awkward posture	Grandjean and Hünting (1977)
Lack of height adjustability	Musculoskeletal symptoms (+)	Hünting et al. (1980)
		Hünting et al. (1981)
		Mandal (1987)
- Table: Height	Musculoskeletal symptoms	Hünting et al. (1981)
Width	Working posture	Mandal (1987)
Depth		Coniglio and Paci (1987)
Lack of Leg room		Pot et al. (1987)
- Chair: Height	Musculoskeletal symptoms	Grandjean (1984)
Backward seat slope	Working posture	Lu et al. (1993)
Instability	Fatigue	Mandal (1984)
Discomfort	Headache	Pot et al. (1987)

(Table con'd.)

*NET EFFECT OF THE POSSIBLE RISK FACTORS:
(+) Positive effect. Higher level of risk factor is related to more symptoms;
(-) Negative effect. High level of risk factor is related to less symptoms.

(Table 3.1 con'd.)

Possible Risk Factors	Net Effects*	Authors
Workstation design		
- Lack of copy holder	Awkward posture (+) Musculoskeletal symptoms (+) Visual fatigue (+)	Cakir et al., (1980) Lu et al., (1993b) Pot et al., (1987)
- Lack of footrest	Awkward posture (+)	Pot et al., (1987)
Environment		
- High contrast between document and screen	Visual symptoms (+)	Läubli et al., (1983)
- High oscillating luminance of characters	Visual symptoms (+)	Läubli et al., (1983)
- Illumination at keyboard - Illumination at worksurface	Visual symptoms (+)	Sauter (1984)
- Presence of a window in the visual foreground	Visual symptoms (+)	Schleifer et al., (1990)
- Illumination at keyboard x Illumination at display	Visual symptoms (+)	Schleifer et al., (1990)
- Inadequate workplace dimension	Visual symptoms (+) Constrained posture (+)	Läubli et al., (1983)
- Discomfort with the temperature, humidity and ventilation conditions	Headach (+) fatigue (+) Stomach discomfort (+)	Lu et al., (1993b)

(Table con'd.)

*NET EFFECT OF THE POSSIBLE RISK FACTORS:
(+) Positive effect. Higher level of risk factor is related to more symptoms;
(-) Negative effect. High level of risk factor is related to less symptoms.

(Table 3.1 con'd.)

Possible Risk Factors	Net Effects*	Authors
Psychosocial factors		
- Task control	Psychological stress (-)	Carayon et al., (1993)
- Work pressure - Surges of work load - Lack of job security - Lack of social support	Psychological stress (+) Upper extremity symptoms (+)	Hajnal and Carayon (1993) Järvenpää et al., (1993) Lu et al., (1993) Miezio et al., (1987) Rogers et al., (1990) Sauter et al., (1992)
Psychological stress - Fatigue - Anxiety - Depression	Upper extremity symptoms (+)	Lim and Carayon (1993)
Working posture		
- Postural stress	Musculoskeletal discomfort (+)	Boussenna et al., (1982) Hünting et al., (1981) Lift and Pheasant (1984) Sauter et al., (1983)
- Awkward posture	Upper extremity symptoms (+)	Grandjean et al., (1982) Hünting et al., (1981) Lim and Carayon (1993) Maeda et al., (1982) Puhakainen et al., (1993)
- Forward inclination of the head	Musculoskeletal symptoms (+) Headache (+)	Stewart (1979) Travell (1967) Robinson (1980)

(Table con'd.)

*NET EFFECT OF THE POSSIBLE RISK FACTORS:
(+) Positive effect. Higher level of risk factor is related to more symptoms;
(-) Negative effect. High level of risk factor is related to less symptoms.

(Table 3.1 con'd.)

Possible Risk Factors	Net Effects*	Authors
Work Posture		
- Repetitive movement	Upper extremity symptoms (+)	Lim and Carayon (1993) Puhakainen et al., (1993)
- Amount and frequency of vertical head movement	Headaches and postural discomfort (-)	Collins et al., (1990)
Interactions of risk factors:		
- VDT use x work pressure x work atmosphere	Eye symptoms (+) Musculoskeletal symptoms (+) Headache symptom (+) General fatigue and nervousness (+)	Pot et al., (1987)

*NET EFFECT OF THE POSSIBLE RISK FACTORS:
(+) Positive effect. Higher level of risk factor is related to more symptoms;
(-) Negative effect. High level of risk factor is related to less symptoms.

Table 3.2. Summary of possible causal relationships

	Direct Causes or Significant Correlations	Indirect Causes	
		Risk Factors	Mediators
Musculoskeletal discomfort	• Demographics - Age - Sex - Prior medical conditions • Task - Exposure to VDT use • Workstation design - Screen height and adjustability - Keyboard height, thickness, and lack of height adjustability - Table height, width, depth, and lack of leg room - Chair height, seat slope, stability, and comfort - Lack of copy holder • Psychological stress - Fatigue - Anxiety - Depression • Posture - Posture stress - Awkward posture - Repetitive movement	• Psychosocial factors - Work pressure - Work pace control • Workstation design - Screen height - Lack of copy holder - Keyboard height - Seat slope	• Psychological stress - Fatigue • Awkward posture • Repetition • Awkward posture • Posture stress

(Table con'd.)

(Table 3.2 con'd.)

	Direct Causes or Significant Correlations	Indirect Causes	
		Risk Factors	Mediators
Visual fatigue	• Demographics - Eye quality (wearing glasses) • Task - Exposure to VDT use - Rest pauses • Workstation design - Screen legibility - Screen glare - Lack of copy holder • Environment - High contrast between document and screen - High oscillating luminance of characters - Presence of window in the visual foreground - Illumination at keyboard - Illumination at worksurface	• Inadequate workplace	• Constrained posture
General health complaints	• Task - Exposure to VDT use - Type of VDT tasks • Work environment - Discomfort with temperature, humidity, and ventilation conditions • Posture - Forward inclination of the head - Repetitive movement	• Exposure to VDT use	• Perceived Job characteristics

(Table con'd.)

(Table 3.2 con'd.)

	Direct Causes or Significant Correlations	Indirect Causes	
		Risk Factors	Mediators
Psychological stress	• Demographics - Age - Marital status • Task - Exposure to VDT use - Type of VDT tasks • Environment - Discomfort with temperature, humidity, and ventilation conditions • Psychosocial factors - Task control - Work pressure - Work pace control - Lack of social support		
Awkward work posture	• Psychosocial factors - Work pressure - Work pace control • Environment - Inadequate workplace dimension		
Psychosocial factors	• Demographics - Sex - Age • Exposure to VDT use		

3.2 RESEARCH APPROACHES

3.2.1 EXPERIMENT VS. SURVEY

Research with VDTs has been designed to develop and test hypotheses about effects of VDTs on the operators: Is there an effect? Is it harmful? What are the causes and mechanisms?

Tests of these hypotheses have been made in two ways. One approach is to conduct carefully controlled experiments; and another approach is to conduct field surveys; most research falls into the second option. The survey approach is generally used for exploratory purposes. The experiment approach is used for validating the hypothesized causal relationship found in the survey study.

By using the experimental approach, the researcher designs the number and level of the hypothesized causal variable and randomly assign the people to each group. For example, one could randomly assigns people to the group using the monitor with a different height to perform word processing tasks and examine the effect of the screen height on typing performance and physical discomfort. In this way, the researcher may find the suspected causal relationship, such as reported by Lu et al. (1993) for examining the effect of screen height on typing performance and discomfort; Hagberg and Sundelin (1986) for examining the discomfort and load on the upper trapezius muscle when operating a word-processor; and Brand and Judd (1993) for examining the angle of hard copy and text-editing performance.

There are several types of survey designs: (1) One-shot questionnaire survey. This is the most common survey method. In a one-shot design, one sample of subjects is questioned only once, such as the studies reported by Hünting et al. (1981), Läubli, et al. (1981), Lu et al. (1993a and 1993b) and Smith et al. (1992). (2) Longitudinal study. These are of three types: a) Before/After design - where the same group of subjects is questioned before and after a particular event, e.g. before and after implementation of a new computer system (Puhakainen et al., 1993); b) Repeated design - where the same group of subjects is questioned several times over a period of time, or by using a diary style (Bergqvist et al., 1990; Collins et al., 1990); and c) Time series. In this design, information is collected over a period of time, from similar samples of people, but the participants may change from one occasion to the next, such as the study reported by LeGrande (1993).

The experiment study offers an undeniable advantage. Using well-designed experiments, one can control competing explanatory variables by randomly assigning people to conditions that vary only in the variable hypothesized to be causal. However, carefully controlled experimental research has some disadvantages. Compared with survey research, the cost of data collection per respondent is high. Special laboratory conditions must be created just to collect the data, and only a limited number of subjects can occupy such facilities at any one time. Consequently, large sample databases can not be economically generated in terms of time and financial costs. Another disadvantage is that most carefully controlled research, by the act of establishing the controls, creates an artificial situation that may not generalize to typical working environments (National Research Council, 1983). The subjects under the experiment condition do not have the feeling of real work situation. For example, the subjects may not worry about the loss of job security through automation, nor do they experience the excitement of meeting a new challenge on the job. They do not find themselves in a changed career situation to which they may be resistant, nor do they have the choices or variety of tasks that might characterize a real job. Consequently, the results may not generalize to people who choose jobs with VDTs over jobs without such technology or to people who are in jobs they have already learned to perform without VDTs. In short, the results of such experiments may not be generalized to real people in real jobs (National Research Council, 1983). Because of the disadvantage of the experiment approach, some factors such as psychosocial factors or psychological stress and their relationship to physical complaints cannot be studied.

The survey approach avoids this problem. The main advantage of field research is the realism of the phenomena it studies (Rosenberg, 1968; Warwick and Lininger, 1975). However, it has the disadvantage of being unable to fully control competing causes of effects by randomization. The data collected by the one-shot survey approach may involve some variation which results in random correlations. In longitudinal study, a central question is, how long is it necessary or possible to follow-up certain groups of people after a specific change in their VDT use; while trying to measure the effect on well-being or productivity (Lindström, 1993)? Because of the disadvantage, the survey study needs to be carefully designed and the sampled population needs to be well defined and controlled.

Several studies adopted the following approach: using the survey method to discover the health complaints and associated factors and then conducting experiments to further validate the relationships (Life and Pheasant, 1984). This approach integrates the survey and experiment into one study. Another way to integrate the survey and experiment approach is to design the experiment and then conduct the study in a real workplace using real workers to perform their routine job (Mandal, 1987; Wall et al., 1992).

The research approach and design chosen for the study will depend on the nature of the variables the researcher is investigating.

3.2.2 MEASUREMENTS

The measurement used for the evaluation of VDT work environment and health symptoms experienced by operators can be classified as subjective and objective. Subjective measurements are the person's opinion regarding a particular event and usually used in the survey study. In some experiment studies, the subjective measurements are also used for the discomfort rating or preference rating, such as the studies by Lu et al. (1993) and Brand and Judd (1993). Objective measurements are the measurements which are based on certain criteria. The objective measurements are usually used in the experiment study. They have also been used in survey studies for evaluating health conditions and the physical work environment (Burgqvist et al., 1991; NIOSH, 1992).

3.2.2.1 MEASUREMENTS FOR HEALTH SYMPTOMS

There are four types of measurements for evaluating the health symptoms among VDT operators: self-reported measures, medical examinations, physiological measures, and postural measures. A self-reported measure is subjective while the other three are considered to be objective.

The self-reported measure is widely used in various survey and experiment studies for the symptoms of eye, muscle, and general physical problems. It usually requires the operators to report the frequency and/or severity of the symptoms they have experienced according to a certain scale. It has the advantage of low cost and immediate response. The disadvantage is that some operators may over- or under-report the symptoms because of some other factors that may affect the person's reporting behavior, such as misunderstanding the wording or the presence of other symptoms. The subjective reports of discomfort have been questioned for its validity (Howarth and Istance, 1986). However, it is continuously widely used because it is expensive or some times impossible to repeat the identical questionnaire to validate the symptoms.

Medical examination has been used in survey studies for the examination of musculoskeletal disorders, such as tendon related upper extremity disorders, muscle-related upper extremity disorders, nerve entrapment syndromes, and joint-related disorders (Bergqvist et al., 1990; Läubli et al., 1981; Hünting et al., 1981; NIOSH, 1992). The advantage of medical examination is it's reliability in determining illnesses from symptoms detected with the survey. However, it requires medical specialists, special equipment, longer time and has higher costs.

Some studies have measured physiological parameters to indicate the symptoms, primarily muscular or eye fatigue. Saito et al. (1993) states that visual comfort in VDT work can be evaluated by analyzing several physiological responses of the eye. Such physiological responses as critical flicker frequency (CFF), accommodation, pupil size, eye movements are the efficient indices of visual fatigue (Saito et al., 1993). Lunn and Bank (1986) and Watten (1992) correlated visual contrast sensitivity and visual acuity to visual fatigue. Muscle load has been assessed by recording electromyography (EMG) from upper trapezius muscle in the study by Hagberg and Sundelin (1986). Electroencephalogram (EEG) and heart rate (HR) have also been correlated with the boredom of repetitive tasks such as data entry (Floru et al., 1985). Urinary excretion of catecholamine, urinary excretions of aldosterone, blood pressure, and heart rate have also been used to correlate with fatigue (Gao et al., 1990; Tanaka et al., 1988; Tanaka et al., 1989).

Posture change has been suggested to be an indicator of general and localized muscular fatigue (Delvolve and Queinnec, 1983; Kogi, 1982; Swanson and Sauter, 1993). Swanson and Sauter (1993) conducted a laboratory study about VDT operators' working posture and found a significant increase in fidgets over the workday. Additionally, operators' were found to spend more time in postures indicative of fatigue by the end of the workday.

The advantage of the medical examination and physiological measurements are that they objectively detect the illness experienced by the operator. However, some symptoms and discomforts may not be reflected in the medical examination. Unless large samples are used, medical examination can provide very little information to on health symptoms and their correlation with working conditions.

Medical examination, physiological measurements, and postural measures all require special equipment or instruments and may be more expensive when compared with subjective reporting.

3.2.2.2 MEASUREMENTS FOR PHYSICAL WORK CONDITIONS

As that of health complaints, subjective and objective measures have been used in evaluating the physical work conditions and the subjective measures have been criticized.

Subjective measurements have been used to collect subjective ratings of physical workplace conditions, such screen height, keyboard height, the comfort with chair, screen glare, lighting conditions, etc. In an extensive evaluation of VDT work and health effects, the World Health Organization (1987) cited 12 field studies that examined the relationship between display or workroom characteristics and visual complaints. Seven of these studies were based on subjective ratings of physical workplace conditions. The use of subjective measurements for this purpose has been criticized (National Research Council, 1983).

Objective measurements are those measurements made by the investigator and based on a certain criteria, such as lighting conditions, reflect screen glare, keyboard height, screen height, etc. Some studies have correlated these objective measurements with visual and ocular discomfort (Knave et al., 1985; Laubli et al., 1981; Padomos and Pot, 1987; Sauter et al., 1983; Schleifer et al. 1990; Stammerjohn et al., 1981). However, in the study by Schleifer et al. (1990), the objectively assessed glare variables failed to have any apparent influence on visual system strain. On the other hand, subjective reports of "glare at the workstation" were associated with increased strain and could explain a certain amount of the variance in the ocular and perceptual discomfort scale. The authors suggested that VDT users' perceptions of certain, potentially stressful, lighting conditions (e.g., glare) may be more sensitive or valid than measures based upon efforts to quantify these lighting conditions in a more objective manner.

It is apparent that both objective and subjective ratings are important for evaluating the VDT system.

3.3 DATA ANALYSIS METHODOLOGY

In early studies of VDTs, the following data analysis methods were commonly used: descriptive data analysis (frequency table, histogram, etc.) and univariate analysis, i.e., correlation analysis (Pearson correlation), t-test, analysis of variance, and regression. There was an emphasis on correlation and multiple regression techniques to link variables. Conclusions about the risk factors which might have an effect on the health complaints were generally based on the test of significance of the correlations or the univariate analysis. The advantage of the univariate test is its simplicity. The disadvantage is that when the number of variables increases, the number of tests increases. This may result in increased error. Another disadvantage is that univariate approach test the relationship between one dependent variable and one or more predictors without considering the effect of other dependent variables. This may lead to wrong conclusions about the relationship between the dependent variables and predictors.

The National Research Council (1983) suggested that a multivariate approach should be used because of the complex nature of the VDT system. VDT operators work within a complex system in which many variables interact, probably in complex ways, to affect their well-being. The use of multivariate techniques is essential to understanding the interplay among the variables. It is stated that "we do not yet have sufficient knowledge about which variables are important and how they may interact" (National Research Council, 1983, p.43).

In this section, univariate and multivariate analysis methods are reviewed as preparation for the data analysis used in this study.

3.3.1 DESCRIPTIVE STATISTICS

Frequency tables, means, medians, ranges, standard deviations, histograms, and plots are commonly used in VDT literature for illustrating the demographic data (Bergqvist et al., 1990), the prevalence and pattern of the health complaints (Bergqvist et al., 1990; Hagberg and Sundlin, 1986; Horgen and Aaras, 1993; Lu et al., 1993b), measurements (Grandjean et al., 1984; Hünting et al., 1981; Ong et al., 1988), and conditions of the workstation and work environment (Hünting et al., 1981; Schleifer et al., 1990).

Descriptive statistics is a useful tool to summarize the general information in the sampled population. To describe the observations that might occur in a sample more completely, the concept of the probability distribution is used.

3.3.2 UNIVARIATE ANALYSIS

3.3.2.1 CORRELATION MEASURES

Correlation measures the closeness of a linear relationship between two variables. If one variable x can be expressed exactly as a linear function of another variable y, then the correlation is 1 or -1, depending on whether the two variables are directly related or inversely related. A correlation of zero between two variables means that each variable has no linear predictive ability for the other. However, the two variables have equal status in that either may be the cause of the other or both may be caused by some other variable(s) (Barker and Barker, 1983, p8). Therefore, causation cannot be inferred from simple correlations.

Pearson product-moment correlation ($r = \Sigma\, Z_X Z_Y / n$) is the most commonly used method to measure association between two continuous variables. Spearman's rank-order correlation coefficient is a nonparametric measure that is calculated as the correlation of the ranks of the data. It is appropriate only when both variables lie on an ordinal scale.

In the VDT literature, correlation analysis has been used for examining the association among health complaints and demographics, workstation, physical and the social environment (Sauter, 1983). Levy and Ramberg (1987) and Lu et al. (1993b) used correlation analysis to examine the relationship among various health complaints (i.e., visual fatigue, musculoskeletal symptoms, and general physical symptoms).

3.3.2.2 ANALYSIS OF VARIANCE, T-TEST, CHI-SQUARE TEST

When comparing the means between two groups, t-test and chi-square test are commonly used (Hünting et al., 1981; Läubli et al., 1981; Levy and Ramberg, 1987). Many experiments involve more than two levels of a factor and/or more than one factor (or independent variable). Analysis of variance (ANOVA) is thus used to compare the means. ANOVA can be used to compare the means when there are any number of independent variables, but the method allows for only one dependent variable. The relationship between the dependent variable and the separate independent variables may be assessed as well as the possible interaction of independent variable on the dependent variable.

3.3.2.3 REGRESSION ANALYSIS

Regression analysis is the analysis of the relationship between one variable and another set of variables. The relationship is expressed as an equation that predicts a response variable (also called a dependent variable) from a function or regressor variable (also called independent variables, predictors, explanatory variables) and parameters. The parameters are adjusted so that a measure of fit is optimized. For example, the equation for the *i*th observation might be:

$$y_i=\beta_0 + \beta_1 x_i + \varepsilon_i \tag{3.1}$$

where y_i is the response variable, x_i is a regressor variable, β_0 and β_1 are unknown parameters to be estimated, and ε_i is an error term. Multiple regression allows for more than one independent variable but only one dependent variable.

There are several methods of model selection. One of the methods that is used most commonly in the VDT literature is stepwise regression (Lu et al., 1993b; Schleifer et al., 1990). This method starts with no variables in the model and adds variables one by one to the model. At each step, the variable added is the one that maximizes the fit of the model given previously added variables. In the mean time, it deletes the variable with the smallest contribution to the model if it is no longer important. The criteria for entry into the model and for remaining in the model can be specified. Another model selection method used in the literature is to use all the regressors to fit the regression model, such as Collins et al. (1990). The stepwise method has the advantage of selecting the most important predictors and avoiding multi-colinearity problem when there are many predictors as in VDT field study and these variables possibly are inter-related. The disadvantage of the stepwise regression is that it may miss some important variables since these variables might be taken out before other variables coming into the model. The use of the full model can examine the effects of all the predictors but may have the multi-colinearity problem.

The proportion of variance of the response that can be explained by the regressor variables is R^2. Whether a given R^2 value is considered to be large or small depends on the context of the particular study. In field study, an R^2 of 0.30 might be considered large, while in experiment study, this value might be considered small.

The adjusted R^2 statistic is an alternative to R^2 that is adjusted for the number of parameters in the model. The adjusted R^2 statistic is calculated as

$$ADJRSQ = 1 - [(n-i)(1-R^2)/(n-p)] \tag{3.2}$$

where n is the number of observations used in fitting the model, and i is an indicator variable that is 1 if the model includes an intercept, and 0 otherwise.

Cp is another criterion for selecting a model. It is a measure of total squared error. When the right model is chosen, the parameters estimated are unbiased, and this is reflected in Cp near the number of parameters p in the model (SAS/STAT User's Guide, p.1400).

Many studies have used multiple regression technique to find the predictors of the visual and musculoskeletal symptoms among the variables of workstation, physical and social environment (Lu et al., 1993b; Schleifer et al., 1990).

3.3.3 MULTIVARIATE ANALYSIS

Multivariate analysis deals with the data which has simultaneous measurements on many variables. Some objectives of multivariate analysis methods are as follows: (1) Data reduction or structural simplification. The phenomenon being studied is represented as simply as possible without sacrificing valuable information valuable information and this may make interpretation easier, (2) Investigation of the dependence among variables. The nature of the relationships among variables is of interest. Are all the variables mutually independent or are one or more variables dependent on the others? (3) Hypothesis construction and testing. Specific statistical hypotheses, formulated in terms of the parameters of multivariate populations, are tested. This may be done to validate assumptions or to reinforce prior convictions (Johnson and Wichern, 1992).

3.3.3.1 MULTIVARIATE ANALYSIS OF VARIANCE (MANOVA)

MANOVA is essentially ANOVA but with multiple dependent variables. These dependent variables to some degree measure the same thing, i.e., there are high correlations among these dependent variables. MANOVA allows one to determine the effect of the independent variables on the dependent variables as a whole. It looks at the picture between the dependent and independent variables more comprehensively. It is very useful in the VDT research. For example, there are usually many measures for evaluating eye fatigue, i.e., sore eyes, tire eyes, burning eyes, etc., when examining the effect of age on the eye symptoms, MANOVA is a good tool to use. Unfortunately, no study has employed this approach.

3.3.3.2 FACTOR ANALYSIS

Factor analysis is a method to describe, if possible, the covariance relationships among a larger number of variables in terms of a few underlying, but unobservable, random quantities called factors. The factor model is motivated by the following arguments. Suppose variables can be grouped by their correlations. That is, all variables within a particular group are highly correlated among themselves but have relatively small correlations with variables in a different group. It is conceivable that each group of variables represents a single underlying construct, or factor, that is responsible for the observed correlations. For example, correlations from the group of symptom ratings dry eyes, tired eyes, red eyes, and burning eyes suggests an underlying "ocular discomfort." Another set of variables, which rate pains or discomfort in the neck, shoulder, upper back, and arms, corresponds to another factor, "upper extremity musculoskeletal symptoms." It is this type of structure that factor analysis seeks to confirm.

The factors can be extracted using several criteria differing in how to define "good fit". The common methods of parameter estimation of the common factors are principal component factor analysis, principal factor analysis, iterated principal factor analysis and Maximum-likelihood factor analysis. The loadings of the variables in each factor indicate the contribution of the variables to this factor. The sum of square of the loadings in each factor, called communality, constitutes the total variance explained by this factor, which indicates the importance of the factor in study.

The original factor matrix may not be readily interpretable, therefore, it is usual practice to rotate them until a "simpler structure" is achieved. There are several rotation methods. The most commonly used is the Varimax ratio, which minimizes the number of variables that have high loadings on a factor to enhance the interpretability of the factors. Other commonly used factor rotation methods are Quartimax and Promax rotation.

Factor scores are the estimated values of common factors. These quantities are often used for diagnostic purposes as well as inputs to a subsequent analysis, such as regression.

There are many decisions that must be made in any factor analytic study. Probably the most important decision is the choice of m, the number of common factors. Most often, the final choice of m is based on some combination of (1) the proportion of sample variance explained, (2) subject matter knowledge, and (3) the "reasonableness" of the results. The choice of solution method and type of rotation are less crucial decisions. In fact, the most satisfactory factory analyses are those where rotations are tried with more than one method and all the results substantially confirm the same factor-structure.

Factor analysis was used by Schleifer et al. (1990) on the visual discomfort items in the survey sample. A two-factor solution accounting for 72% of the total variance was generated. One factor, corresponding to "ocular" discomfort, consisted of five items: tearing/itching eyes, burning eyes, sore eyes, red eyes, and dry eyes. The second factor, corresponding to "perceptual" discomfort, consisted of two items: blurred vision and double vision. The factor scores were then used in the regression analysis to find the associated risk factors.

3.3.3.3 CANONICAL CORRELATION ANALYSIS

Canonical correlation analysis seeks to identify and quantify the associations between two sets of variables. Canonical correlation analysis focuses on the correlation between a linear combination of the variables in one set and a linear combination of the variables of in another set. The idea is first to determine the pair of linear combinations having the largest correlation. Next, we determine the pair of linear combinations having the largest correlation among all pairs uncorrelated with the initially selected pair. The pairs of linear combinations are called the canonical variables, and their correlations are called canonical correlations.

Canonical correlations measure the strength of linear association between the two sets of variables. The maximization aspect of the technique represents an attempt to concentrate a high-dimensional relationship between two sets of variables into a few pairs of canonical variables. Plots of the canonical variables can be useful in examining multivariate dependencies. Canonical correlation analysis has been used in the VDTs studies.

3.3.4 SUMMARY

Descriptive statistics and univariate analysis are simple tools to describe the population and find the association among variables. However, univariate analysis allows only one dependent variable. In VDT literature, especially in field study, there are often multiple variables measured on a similar phenomenon, e.g., eye symptoms. The multivariate approach allows us to understand the phenomenon more comprehensively.

CHAPTER 4

RATIONALE

Literature shows that there is increased concern about the possible "adverse health effects" caused by VDT work and its environment. The prevalence of musculoskeletal disorders and visual fatigue has been recognized. The contribution of ergonomics factors and environment to visual and musculoskeletal complaints in VDT work is widely identified. However, the interacting relationships between the discomforts and their possible causes remain undefined. There has been little empirical research to validate the probable factors involved, to define the interrelationships among these factors, and to rank their relative importance. The deficiency may be due to the fact that although the signs and symptoms and their associated impairments have been thoroughly investigated, the exposure conditions until now have been analyzed only superficially and are incomplete. The whole picture of variables in a VDT workstation system has not been made clear.

A VDT workstation system consists of a user, a computer system (hardware and software), a workstation (supporting furniture), a physical environment, and social environment (work organization). The system is complicated in that each system component (e.g. the user, computer system, etc.) has many variables, and these variables are interrelated not only within the component but also between the components.

The literature review shows that there are seven categories of variables that may have effect on VDT operators' health, i.e., demographics, tasks, workstation design, work environment, psychosocial factors, work posture, and psychological stress, and that these variables may be interrelated. However, no study has been conducted to examine the effect of these factors simultaneously and the interrelationships among these risk factors comprehensively.

The research questions are: what VDT factors are most important to a specific category of physical complaints? how do these seven categories of risk factors affect the physical symptoms experienced by VDT operators, and what are the interactions among these risk factors? (see Figure 4.1)

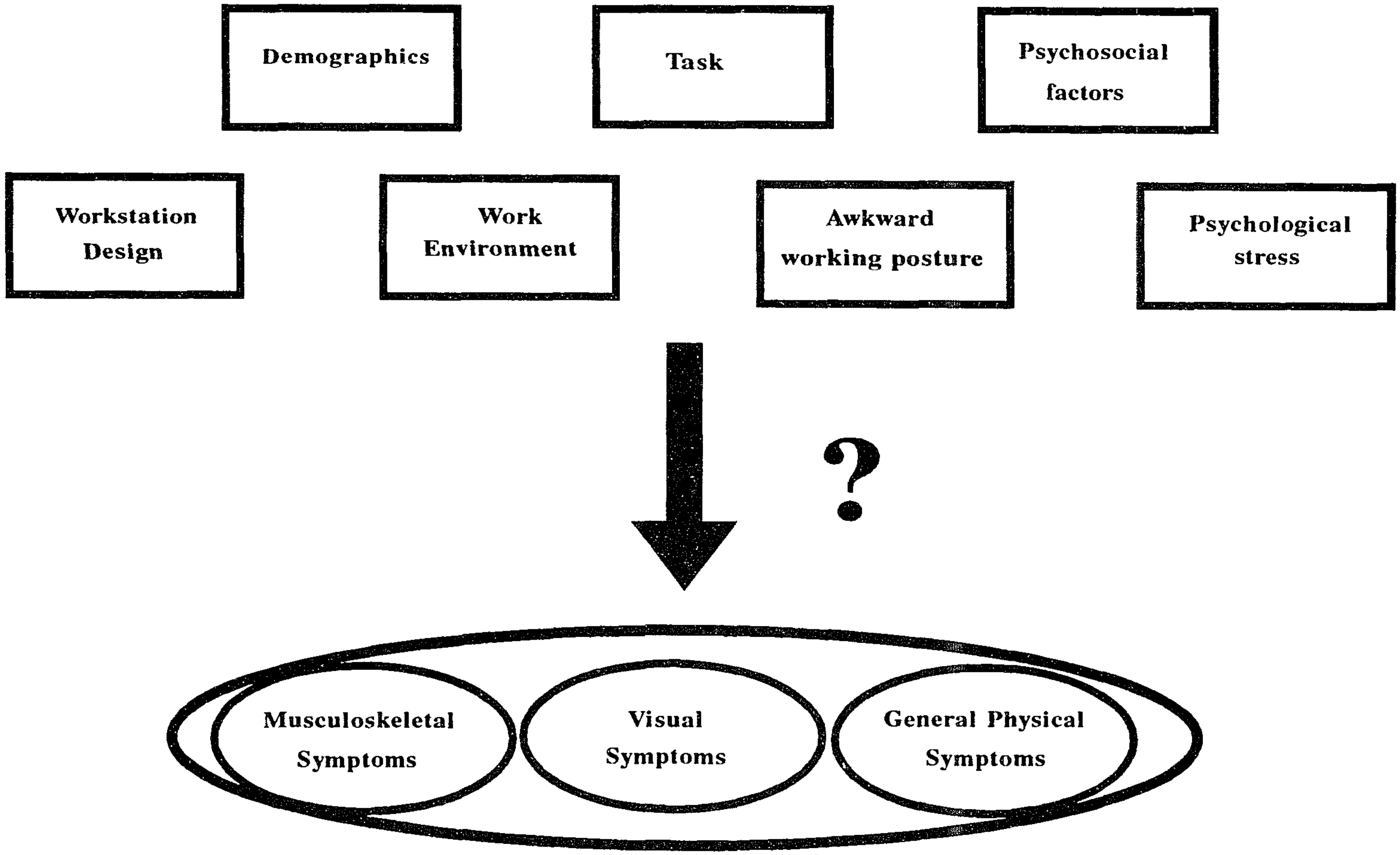


Figure 4.1 Research questions

CHAPTER 5

METHODS AND PROCEDURES

5.1 RESEARCH PLAN

As stated in Chapter 1, the objectives of this research were to identify the most important risk factors in the VDT work station system and examine how these factors influence the physical symptoms experienced by VDT operators. The research plan proposed for the above purpose is illustrated in Figure 5.1. This research consisted of four parts: research model development, methodology development, field study, and data analysis.

In order to examine the relationship between the risk factors and the physical complaints, a framework was needed to decide the hypothesized relationship based on past research. To collect the health complaints, it was necessary to conduct a survey study at a real work place. A survey was designed for collecting data and analyzing the relationships in the research model. A methodology for the posture analysis was developed to assess the operator's working posture and its effects on the physical symptoms. A field study was then conducted. The data collected from the survey was used to test the hypothesized relationships.

5.2 MODEL DEVELOPMENT

5.2.1 CONCEPTUAL MODEL

A work system consists of the following five elements: (1) the person, (2) the work environment, (3) tasks, (4) technology and (5) the work organization (Smith and Carayon, 1992). These various elements interact when work is being done. Demands are

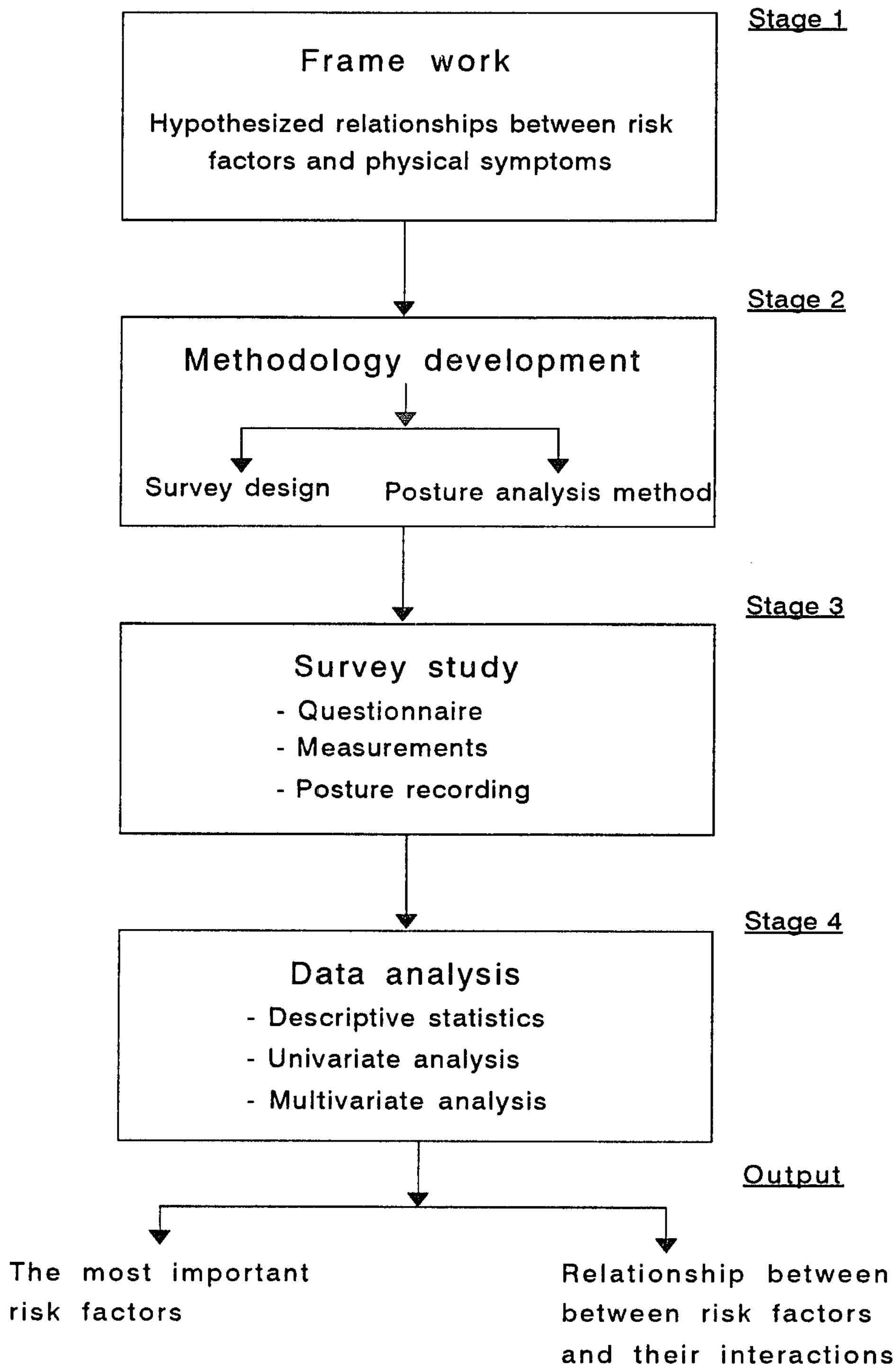


Figure 5.1 Research plan

placed on the individual by the other four elements which create loads that can be healthy or harmful. Harmful loads lead to physical and psychological stress responses that may produce adverse health effects such as cumulative trauma disorders or musculoskeletal stress or visual fatigue.

In a VDT system, the interaction of these element may lead to physical and physiological effects via the ergonomic risk factors or repetition, posture, and duration, and psychological stress. In addition, ergonomic risk factors alone may influence the physical and psychological stress directly. According to the literature, psychological stress can also lead to physical symptoms (Lim and Carayon, 1993; Smith and Carayon; 1992). This relationship is illustrated in Figure 5.2.

This conceptual model shows how the interaction of the system components may result in possible adverse health effect. There are many variables in the proposed conceptual model. For this research, a research model is to be further developed which incorporates the nine categories of variables discussed in Chapter 3 into the model, i.e., demographics, tasks, workstation design, work environment, psychosocial factors, posture, psychological stress, musculoskeletal symptoms, visual symptoms, and general physical symptoms.

5.2.2 RESEARCH MODEL

The proposed research model is shown in Figure 5.3. This model shows the hypothesized relationship among the components in the VDT system based on the literature review in Chapter 3. It is actually a simplified form of the conceptual model shown in Figure 5.2.

There are three levels of variables in the model. The first level consists of the variables of physical symptoms experienced by VDT operators. These physical symptoms are classified into 3 categories, i.e., musculoskeletal, visual, and general physical. Since the purpose of this research is to examine the effect of other risk factors

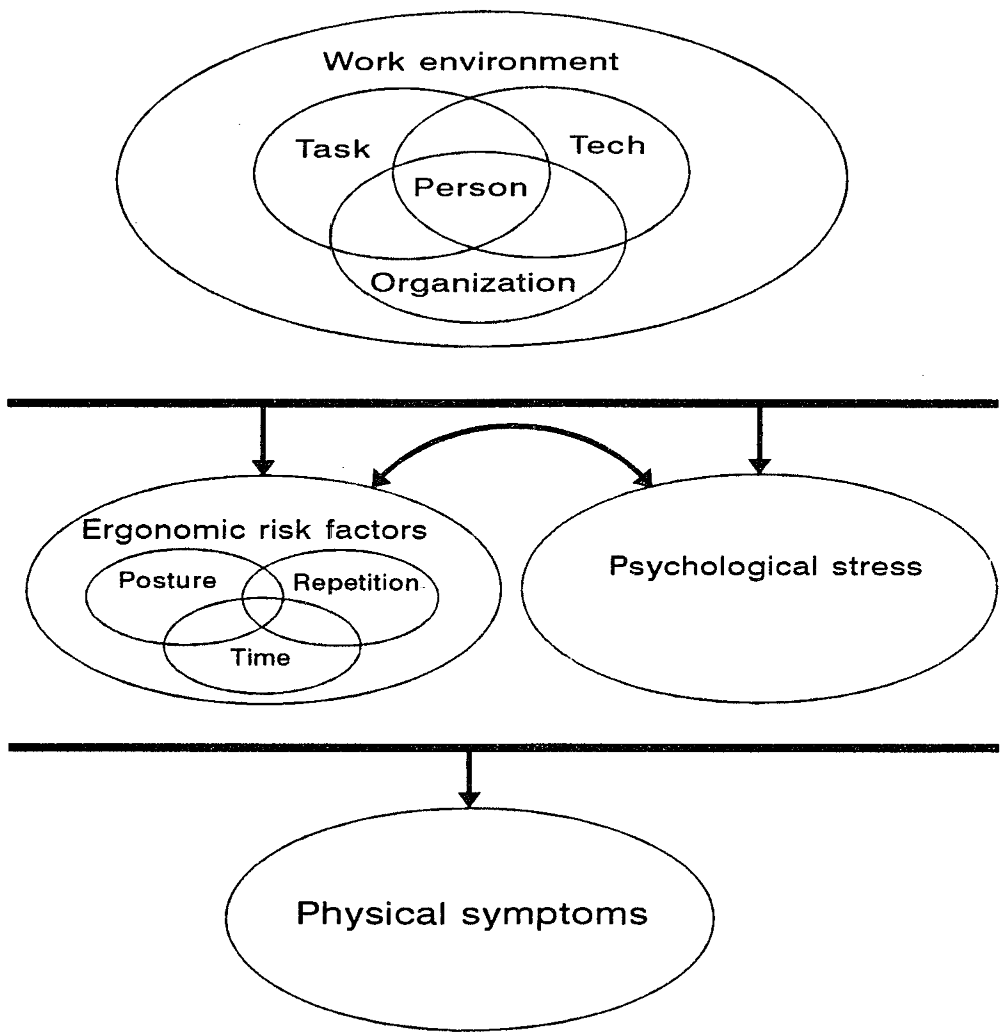


Figure 5.2 A conceptual model

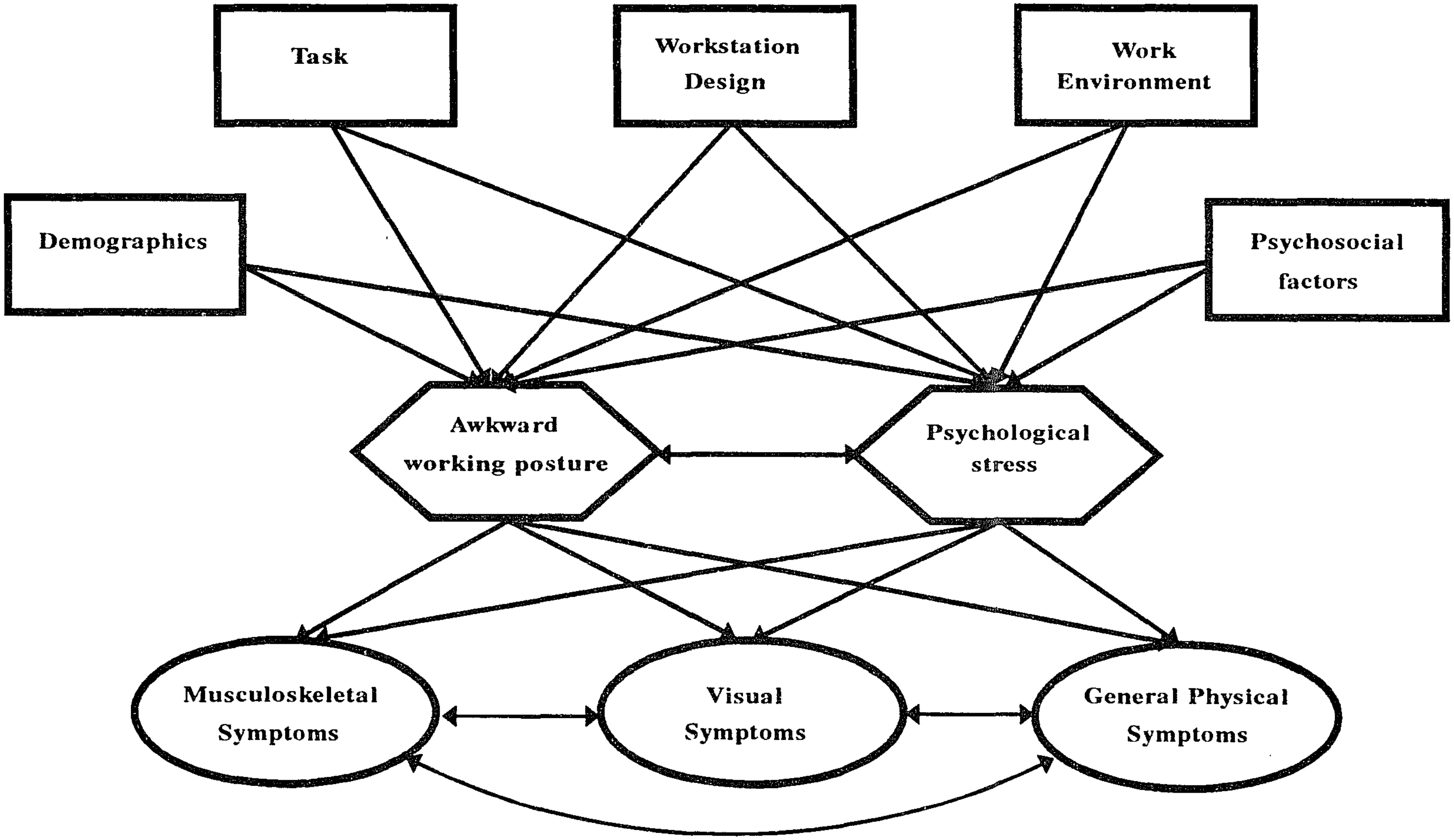


Figure 5.3 A cause-effect model for VDT workstation systems

on these physical symptoms, they are considered as endogenous or dependent variables in the research model. The three categories of physical symptoms are assumed to be inter-related. The second level consists of variables of working posture and psychological stress. The variables of the second level act as mediators, i.e., both "cause" (to the first level variables) and "effect" (to the third level variables). The third level consists of the variables of tasks, workstation design, work environment, and psychosocial factors. They are assumed to be acting as "cause" in the model, so they are exogenous or independent variables. The third level variables have both direct and indirect effects on the first level variables. The direct effects are not drawn in the research model. The indirect effects of the third level variables on the first level of variables (physical symptoms) are via their impact on the second level of variables (awkward working posture and psychological stress).

5.2.2.1 LEVEL I: PHYSICAL SYMPTOMS

The physical symptoms experienced by VDT operators are classified into the following three categories: musculoskeletal symptoms, visual symptoms, and general physical discomfort. Musculoskeletal symptom is defined as the discomfort, numbness, or pain which is related to muscle and nerve systems at any part of body, including neck, shoulders, elbows, wrists, upper back, lower back, hips/thighs, knees, and ankles/feet. Visual symptom is defined as any ocular and visual discomfort including tearing eyes, tired eyes, eye dryness, burning eyes, and blurred vision. General physical symptoms include headaches, stomach discomfort, and ringing ears which do not fall into the other two categories. It is assumed that these health complaints are inter-related based on the past field study (Lu, et al, 1993). This can be interpret as when a person experiences more symptoms in one category, for example, musculoskeletal symptoms, he/she may have more complaints about the symptoms in other categories, such as visual and general physical discomfort.

The following hypothesis is developed:

Hypothesis I: The three categories of physical symptoms, i.e. musculo-skeletal, visual, and general physical symptoms, are highly correlated.

The implication of this assumption is that multivariate instead of univariate approach should be used to examine the effect of risk factors on the physical symptoms.

5.2.2.2 LEVEL II: PSYCHOLOGICAL STRESS AND AWKWARD POSTURE

This research model proposed that the psychological stress and awkward posture should be considered as the key risk factors which mediate the effects of demographics, tasks, workstation, physical work environment, and psychosocial factors on the physical symptoms.

5.2.2.2.1 PSYCHOLOGICAL STRESS

There is accumulating evidence that the stress associated with VDT use may contribute to cumulative musculoskeletal disorders (Sauter et al., 1992; Smith et al., 1981; Smith et al., 1992; Lim and Carayon, 1993). According to Smith and Carayon (1992), psychological stress can lead to an increased physiological susceptibility to cumulative trauma disorders by modifying hormonal responses and circulatory responses that exacerbate the influence of the traditional risk factors of repetition, posture and force. In addition, psychological stress can affect employee attitude, motivation and behavior which can lead to risky behaviors that increase CTD risk. Other literature indicates that the increased stress can lead to increases in the secretion of epinephrine and norepinephrine (Levi, 1972; Frankenhaeuser and Gardell, 1976). An increase in the level of norepinephrine may mean an increase in muscular effort that may lead to muscle tension. Therefore, prolonged exposure to muscle tension can lead to muscle fatigue, which overtime, can lead to chronic musculoskeletal disorders. Psychological stress may also be associated with general physical symptoms such as headache, stomach pain and ringing ears, and visual symptoms through increased muscle tension.

On the other hand, psychological stress may be associated with awkward posture and lead to physical symptoms. For instance, a person under stress may be slouched more than usual which may cause physical discomfort.

The following hypotheses are developed based on above discussion:

Hypothesis II:
Psychological stress directly affects the musculoskeletal symptom complaints, visual symptoms complaints, and general physical health.

Hypothesis III:
Psychological stress and awkward posture are correlated.

5.2.2.2.2 AWKWARD POSTURE

It has been recognized that poor working posture is a potential risk factor for musculoskeletal problems in VDT work (Grandjean, 1987; WHO, 1987). An awkward posture is defined here as one which is maintained by sustained active tension of the musculature and/or by passive loading (compression or tension) of tissue. The requirement to maintain such postures for long periods is considered undesirable, because static muscular tension can only be maintained with the incurrence of certain physiological and psychological costs: the use of energy and the production of waste products, which, in turn give rise to fatigue and discomfort. The effects will occur more quickly under static conditions, as a consequence of ischaemia (a reduction in the blood supply to the muscles caused by their own contraction). The compression of tissue for long period can also lead to acute or chronic symptoms or discomfort or disability (Life and Pheasant, 1984; Tijerina, 1984).

The following hypothesis is developed:

Hypothesis IV:
Awkward posture directly affects the musculoskeletal symptom complaints, visual symptoms complaints, and general physical health.

5.2.2.3 LEVEL III: BASIC SYSTEM COMPONENT VARIABLES

Demographics, tasks, workstation design, work environment, and psychosocial factors are basic variables in the VDT workstation system. These variables inter-correlated with each other and affect on the operator's health.

5.2.2.3.1 DEMOGRAPHICS

Demographic variables, such as age, sex, length of employment, may be associated with physical discomfort through their impact on the posture and psychological stress. People with different age, sex, and use of eye wear may adopt different posture at their work which may result in physical discomfort. Because of individual's characteristics, the tolerance to the stress from the system environment is different. Demographics variables are also assumed to affect the physical discomfort through the interaction with other variables, such as tasks, workstation, work environment and psychosocial variables.

The following hypotheses are developed:

Hypothesis V:
Demographics variables are associated with posture and psychological stress which contribute to the physical symptoms.

Hypothesis VI:
Demographics variables have interactions with task, workstation
design, work environment, and psychosocial factors.

5.2.2.3.2 TASK

VDT work can be classified into four different tasks, data entry, word processing, interactive work/information retrieval, and programming/CAD. As discussed in Chapter 2, each task has its own characteristics and require different amount of work on hands and eyes. Therefore, different VDT tasks may result in different postures that operators use at work. For example, interactive work and informar tion retrieval need intensive reading from the screen which may easily cause slouched posture.

Different VDT tasks are also associated with different levels of psychological stress. Many studies found that monotony is related to data entry work and results in quick fatigue and depression. Prolonged working hours and the time worked with a computer may also be related to fatigue and anxiety.

The following hypothesis is developed:

Hypothesis VII: Task variables are associated with awkward posture and psychological stress which contribute to the physical symptoms.

5.2.2.3.3 WORKSTATION DESIGN

Improper workstation designs constrain working posture and these constraints lead to "posture stress" which in turn leads to physical discomfort. Life and Pheasant (1984) found that increasing the keyboard height above the elbow gives rise to higher levels of discomfort, due to the greater amount of work that must be performed by the shoulder to maintain the hands correctly oriented to the keyboard. In addition, laying the copy script flat on the desk beside the keyboard results in the need for increased muscular activity to support the head while it is craned over to read. In addition, the workstation design contributes to the perceived discomfort of the workstation which may cause the psychological stress.

The following hypothesis is developed:

> **Hypothesis VIII:**
> Workstation variables are associated with awkward posture and psychological stress which contribute to the physical symptoms.

5.2.2.3.4 WORK ENVIRONMENT

Work environment variables include the variables of lighting conditions, work space, noise, and comfort with the temperature, humidity, and ventilation conditions.

Many studies have shown that the work environment is associated with visual symptoms (Läubli et al. 1983; Sauter, 1984; Schleifer et al., 1990). Work environment may also be associated with constrained posture and result in musculoskeletal discomfort (Läubli et al., 1983). Lu et al. (1993b) found that discomfort with the temperature, humidity, and ventilation conditions is also related with headache, fatigue, and stomach ache.

The following hypothesis is developed:

> **Hypothesis IX:**
> Work environment variables are directly associated with visual symptoms.

> **Hypothesis X:**
>
> Work environment variables are directly associated with posture and psychological stress which contribute to physical symptoms.

5.2.2.3.5 PSYCHOSOCIAL FACTORS

Psychosocial factors are associated with psychological stress. Psychosocial factors are important factors contributing to the musculoskeletal symptoms via their impact on awkward posture and psychological stress (Lim and Carayon, 1993).

The following hypothesis is developed:

Hypothesis XI: Psychosocial variables are directly associated with posture and psychological stress which contribute to physical symptoms.

5.2.2.4 SUMMARY

Based on past research, a model which describes the relationship between the seven (7) categories of risk factors and three (3) categories of physical health symptoms, is proposed and eleven hypotheses are formed.

5.3 SURVEY DESIGN

As discussed in Chapter 3, survey has the advantage of realism over the experiment approach. Because of the amount of variables and the complex relationship to be investigated in this research, the survey method is more appropriate than the experimented approach. The survey consisted of three parts, a questionnaire, measurements and posture recording. A questionnaire for the purpose of collecting personal background information, subjective opinions of the tasks, workstation design, environment, and health complaints was designed. A measurement worksheet and a checklist for the objective evaluation of workstation and work environment were also developed. A posture analysis was conducted.

5.3.1 QUESTIONNAIRE DESIGN

Before designing the questionnaire, the specific variables representing each category defined in the research model (Figure 5.3) were identified (see Appendix A). A questionnaire was then designed (see Appendix B).

The questionnaire is divided into the following three parts: (1) background information, which collects the information on demographics, subjective report of the VDT tasks, and psychosocial factors; (2) possible health symptoms, which include musculoskeletal, visual, general physical, and psychological complaints; and (3) computer, workstation, and work environment, which include subjective evaluation of workstation design and work environment.

5.3.1.1 BACKGROUND INFORMATION

Demographics information had the following dimensions: work site (institution), department, sex, age, job title, type of eye wear, the frequency of eye examination, work habit, and exercises. The above information reflects the basic characteristics of the operator.

VDT task information is concerned with the amount of exposure to VDTs and the type of VDT tasks. It was obtained by the following information: length of time at present job, VDT work history, working hours/day, typing speed, the major tasks with VDTs, the time spent using computer continuously, the total time of using computer daily, and the percentage of time spent using mouse.

Psychosocial factors examined in this study are: perceived surges of work load, work pressure, job satisfaction, supervisor support and feedback, and interaction with other people at work (Sainfort, 1990; Carey, 1992). A 4-point scale with end points of 'never' and 'daily' was used for evaluating the response to the surges of workload and work pressure. A 6-point Likert scale with end points of 'strongly disagree' and 'strongly agree' were used to measure the response to the statements regarding the other psychosocial variables stated above (Carey, 1992).

5.3.1.2 POSSIBLE HEALTH SYMPTOMS

Musculoskeletal, visual, general physical symptoms and psychological complaints were collected by using a 5-point scale, i.e., 1 - Never, 2 - less than once a week, 3 - once a week, 4 - several times a week, and 5 - daily.

A body map was used for subjects to indicate the area(s) which they experienced stiffness, ache, pain, numbness, or discomfort (Figure 5.4). As shown in Figure 5.4, the body is divided into nine regions, i.e. neck, shoulders, upper back, low back, elbows,

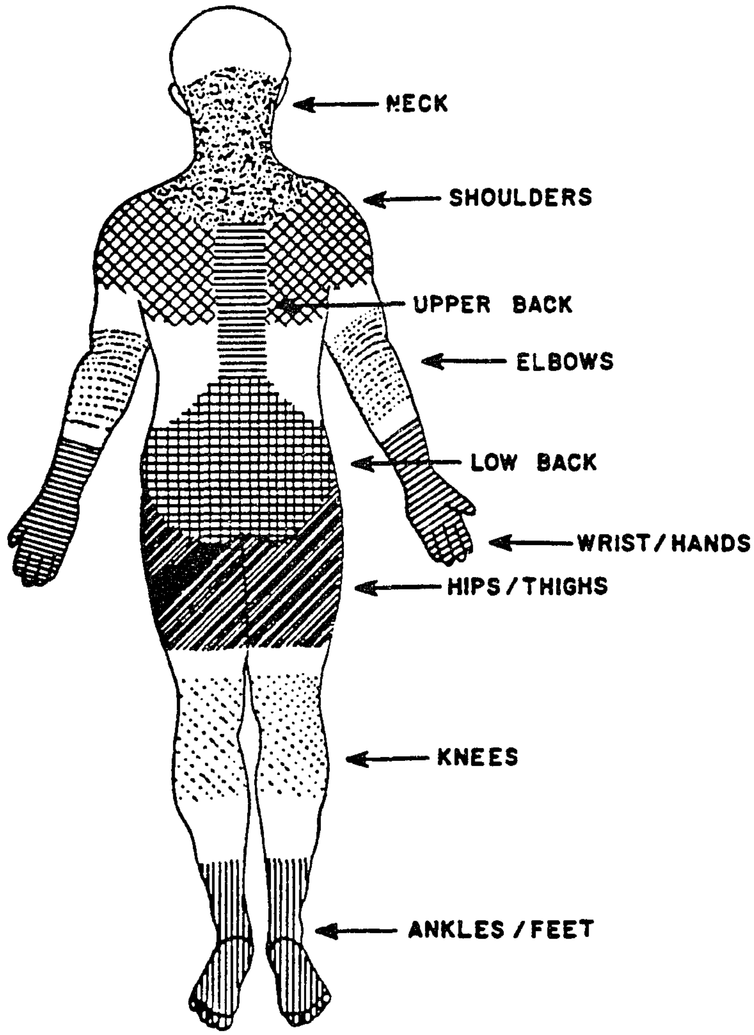


Figure 5.4. Body map used in the questionnaire
(Source: Chaffin and Anderson, 1991, reprinted by permission of John Wiley & Sons, Inc.)

wrist/hands, hips/thighs, knees, and ankles/feet. If the subject indicated the presence of the symptom, a scale was provided for indicating the frequency of the problem. It was also asked whether the problem was associated with any accident and the first time of having the problem.

Visual symptoms were recognized as the following items, tearing/itching eyes, dry eyes, burning eyes, tired eyes, blurred vision/double vision. The first four items corresponded to 'ocular discomfort' and the last one represented 'conceptual discomfort'(Schleifer et al., 1990). A question was also asked for the frequency of changing glasses because of deteriorating vision.

General physical symptoms were recognized as the symptoms of headache/dizziness, ringing ears, and stomach discomfort. The psychological complaints examined by fatigue, anxiety, and depression (McNair et al., 1971; Sainfort, 1990).

5.3.1.3 COMPUTER, WORKSTATION, AND WORK ENVIRONMENT

Workstation information was collected by the subjective evaluation of screen, keyboard, and chair which are the basic hardware of a VDT workstation system.

Screen glare, legibility of screen characters, readability of text on the screen, screen size, and position of screen were evaluated by a 4-point scale, from 1 to 4, representing from excellent condition to poor or uncomfortable condition. A 5-point scale was provided for rating the height of the screen, from 1 to 5, corresponding to 'too high' to 'too low'.

The subjective evaluation of keyboard included the rating of the comfort with the position of keyboard and the height of keyboard. Past research has found that the height of the keyboard is associated with the musculoskeletal discomfort (Hünting et al., 1981). However, the position of the keyboard, i.e., in front of the user or tilted, has not been evaluated.

Chair was evaluated by the height, the comfort with the back rest, and the comfort with the seat pan. The reasons for too high or too low chair were also asked since most chairs used by computer operators were observed to be adjustable in the work place (Lu et al. 1993a).

Work environment was assessed for the illumination of the working area, the comfort level of the illumination, the noise level of the working area, the comfort with the temperature, humidity, and ventilation conditions, the work space, and privacy of the work area.

5.3.2 MEASUREMENT AND CHECKLIST DESIGN

In order to objectively assess workstation design and lighting condition in the workplace, a checklist and measurement worksheet for workstation, lighting condition, and anthropometry data were developed.

The following items at workstation were assessed objectively: computer system, workstation layout, workstation accessories, chair, screen glare, workstation dimensions, lighting conditions, and screen glare (Table 5.1). An anthropometric set was used for the measurement of workstation and dimension. A triple range, light meter made by General Electric was used for measuring the lighting conditions. Measurement technique and landmark for each item are defined in Appendix D. Anthropometric data including height, eye height while sitting, elbow height while sitting, and popliteal height were also measured by using the anthropometry set.

5.3.3 POSTURE RECORDING

The purpose of posture recording was to collect working posture data and investigate the association of posture and other variables in the research model. A posture analysis method was developed and is to be described in section 5.4. The operator's working was recorded for 5-10 min. during his/her normal working period and assumed to represent the operator's dominant working posture in the workplace.

Table 5.1 Objective assessment of workstation and lighting condition

Category	Specific Items
Computer system	• Type of computer • Type of software • Screen size
Workstation layout	• Screen position and keyboard position
Workstation accessories	• Presence of copy holder • Position of copy holder • Presence of wrist rest • Presence of anti-glare screen
Screen glare	• Presence of screen glare • Sources of glare • Proportion of the display affected by screen glare • Degree of image visibility loss due to screen glare • Presence of a window • Presence of curtain or blind at the window
Workstation dimension	• VDT height (center) • Working table height • Keyboard height • Seat height • Viewing distance from screen • Viewing distance from source document
Lighting condition	• Display luminance • Keyboard luminance • Document luminance • Visual foreground luminance - 30° left of the VDT - 30° right of the VDT - Directly behind the VDT • Illumination at screen • Illumination at keyboard • Illumination at source document

5.3.4 SAMPLING METHOD

The ideal way to select survey area is to find health records in different work organizations and to select two areas with one having the most health complaints and the other having the least health complaints. This is hard to do because firstly, there are no records showing the health complaints such as musculoskeletal discomfort and eye fatigue, and secondly, there are no such database in which to search and compare the data.

In order to search for the workplace for this survey, the author contacted several government and private agencies and several departments of LSU which had computer workstations and daily computer users. Our Lady of the Lake Hospital was selected as the study place because: (1) there were many computer users; and (2) this was the only place that permitted the author to enter the workplace and conduct the study. Several departments of LSU were also selected including Penington Biomedical Research Center and some department offices.

Subject were randomly selected in the sampled area based on the following criteria: (1) full time employee, (2) working at present workstation at least three months, and (3) daily computer user.

5.3.5 SURVEY PROCEDURE

The survey procedure consists of three steps: administration of the questionnaire, workstation measurement and evaluation, and video tape of working posture. At each interview, the subject was told about the purpose and procedure of the survey. The survey procedure was continued if the subject agreed to participate the survey.

The questionnaire was given to the subject at each workstation and the subject was asked to return to it the next day. Some subjects answered the questionnaire immediately. It generally took 10 minutes to answer the questionnaire.

The dimensions of workstation, work environment, and anthropometry data were measured. A checklist was used to evaluate the workstation for the type of computer system, software, glare source, etc. Questions were also asked by the investigator for confirming some items on the checklist. It took about 10 to 15 minutes for this step.

The subject was then asked to continue her work. The working posture, workstation, and the surrounding area were then video taped for 5-10 minutes.

5.4 POSTURE ANALYSIS

In order to analyze working postures among VDT operators, a posture scoring system needed to be developed.

5.4.1 BRIEF REVIEW OF POSTURE ANALYSIS METHOD

Various methods have been found in the literature to assess the postures, movements and forces exerted while performing a job and their effect on the physical capacity and capability of the person. Methods to evaluate the working posture can be classified as observation (Priel, 1974; Corlett and Bishop, 1976; Karhu, et al., 1977; Corlett et al., 1979; McAtamney and Corlett, 1993), videotape, optical or frame-grabbing systems (Occhipinti et al, 1985; Keyserling, 1986; Foreman et al, 1988; Tracy and Gray, 1989; Corlett, 1990; Wrigley, et al, 1991). All these methods are undoubtedly useful and are served as the basis of development of the posture analysis method in this research.

Since the data collection in this research will be conducted at a real workplace, the major consideration in developing the posture analysis method here is simplicity and ease-of-use. Compared with other methods, the observation method is simple, quick, and do not require complicated and expensive equipment. The OWAS system (Karhu et al, 1977) and RULA system (McAtamney and Corlett, 1993), which use the concept of numbers to represent postures with an associated coding system, are clear and concise methods which can be used quickly. This is used as a suitable basis for this research.

Most of the literature on neck posture has emphasized discomfort and disorders related to the head inclination angle. Kumar and Scaife (1979) showed biomechanically that small neck flexion angles cause significant muscle contractions. Subjective discomfort rating methods have demonstrated a relationship between forward neck flexion and localized pain (Hunting et al., 1980). Epidemiological studies have found a relationship between awkward neck posture and cervicobrachial disorders (Jonsson et al., 1988).

Laboratory studies have shown that trunk flexion, lateral bending, or twisting increases mechanical stresses on the spinal muscles and intervertebral discs (Anderson et al., 1977; Schultz et al., 1982) and that prolonged trunk flexion causes extreme levels of muscle fatigue (Chaffin, 1973). Epidemiologic studies have shown that sustained static postures of the trunk such as prolonged sitting or forward bending result in increased risk of low back pain (Magora, 1972; Kelsey and Hochberg, 1988). Periodic or repetitive bending and/or twisting of the trunk have also been cited as factors in the development of back pain (Keyserling et al, 1988).

Laboratory studies of the shoulder have shown that prolonged elevation of the arms (glenohumral flexion or abduction) causes extreme levels of muscle fatigue, and in some cases, acute tendinitis (Chaffin, 1973; Hagberg, 1982). The relationship between shoulder elevation and increased risk of tendinitis has been demonstrated in a cross-sectional field study (Hagberg, 1984). Shoulder elevation and extension have been associated with increased risk of a variety of cervicobrachial disorders including thoracic outlet syndrome (Feldman et al., 1983; Armstrong, 1986; Jonsson et al., 1988).

Excessive extension of the wrists may cause symptoms in the hands. Previous studies among accounting workers have shown that the incidence of tiredness, pains and cramps in the right hand increases with the degree of ulna deviation of the same hand (Grandjean, 1984b).

5.4.2 A POSTURE SCORING METHOD

After reviewing the literature, it is seen that the following measurements are important for assessing the working posture: head/neck angle, trunk posture, arm posture, and wrist posture.

To simplify the posture analysis process, only the operator's dominant working posture was analyzed. The dominant posture was defined here as the posture that the operator uses most of the time when he/she working with the computer. It represented the operator's habitual posture and movement in accommodation of the design of workplace and work nature. The basic assumption was that the deviation from neutral sitting position require extra muscle effort to balance the body and therefore may easily cause operator's discomfort and fatigue. Awkward posture and body movement such as twisting or bending sideways could also lead to physical discomfort.

Similar to those observation methods (Priel, 1974; Corlett and Bishop, 1976; Karhu, et al., 1977; Corlett et al., 1979), the body is divided into several segments for the evaluation of posture. Using the concept from OWAS system (Karhu et al., 1977) and RULA system (McAtamney and Corlett, 1993), standard postures for each segment are pre-defined and a score corresponding to the possible risk of each posture are assigned. Because this research concentrates on the posture when the subject is sitting and performing the job, and the major moving part of the body is the head/neck, arms, and trunk, the body is divided into the following six segments for the evaluation of the posture: head/neck, trunk, upper arms, lower arms, wrists, and legs/feet (Figure 4.1). The posture and movement range of each body part are divided into different sections according to the criteria derived through the interpretation of relevant literature. These sections are numbered so that the number one (1) is given to the working posture or the range of movement where the risk factors present are minimal. Higher numbers are allocated to parts of the working posture or movement range with more extreme posture indicating an increasing presence of risk factors causing load on the structures of the body segment.

5.4.2.1 HEAD/NECK POSTURE

The head/neck posture is defined relative to the position of the trunk (Gamberale et al., 1990). If the head and trunk move as a unit, no posture change occurs at the neck. The scores and ranges for the head/neck posture are (Gamberale et al. 1990; Keyserlin, 1990) (Figure 5.5):

- 1. Neural: -10° extension to 20° flexion;
- 2. Flexion: 20° or more flexion;
- 3. Extension: > -10° extension.

If the head/neck posture or the movement is twisted or side-bending, the score is increased by 1 (McAtamney and Corlett, 1993);

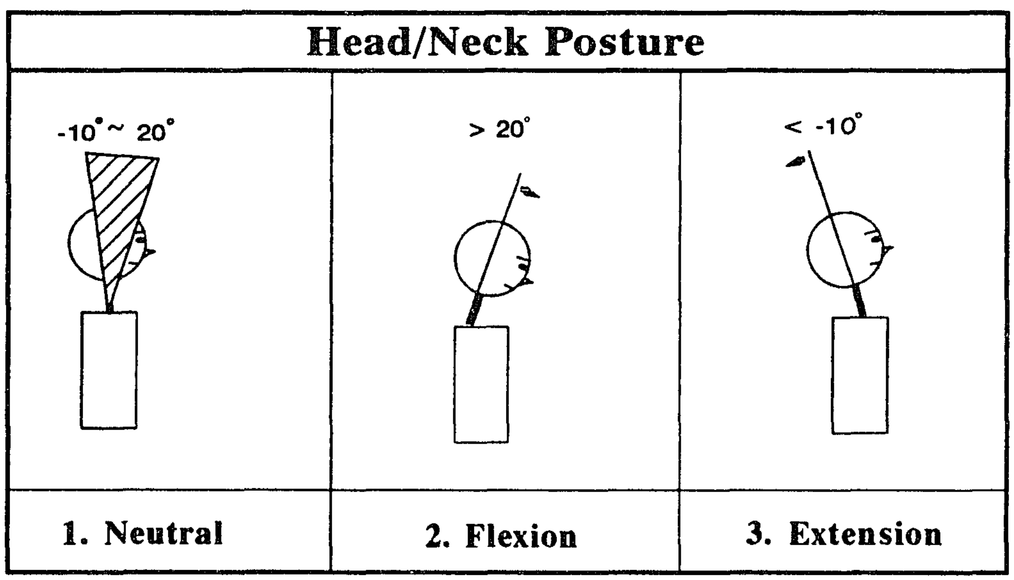


Figure 5.5 Head/neck posture

5.4.2.2 TRUNK POSTURE

The trunk posture is classified according to the following categories and the scores (Gamberale et al. 1990; Keyserling, 1990) (Figure 5.6):

- 1. Neural: -20-0° extension or 0-20° flexion;
- 2. Flexion: >20° flexion.

If the lower back is not well supported, the score for trunk posture is increased by 1; If the trunk movement is twisted or bending sideways, the score for trunk posture is increased by 1; If no movement is observed during the period of recording, the score is increased by 1.

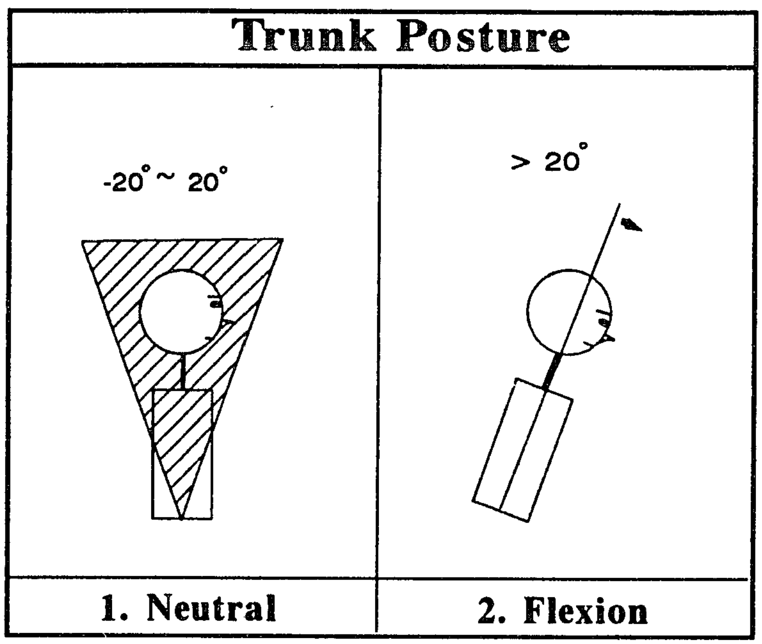


Figure 5.6 Trunk posture

5.4.2.3 UPPER ARM POSTURE

Upper arm posture is measured as the included angle between the trunk and the humerus. The upper arm posture is classified and scored as (Figure 5.7):

- 1. Neural: 20° extension to 20° of flexion;
- 2. Mild flexion: 20-45° flexion;
- 3. Severe flexion: 45° or more of flexion.

If the shoulder is elevated the posture score derived as above is increased by 1; if the upper arm is abducted, the score is also increased by 1; if the weight of the arm is supported then the posture score is decreased by 1.

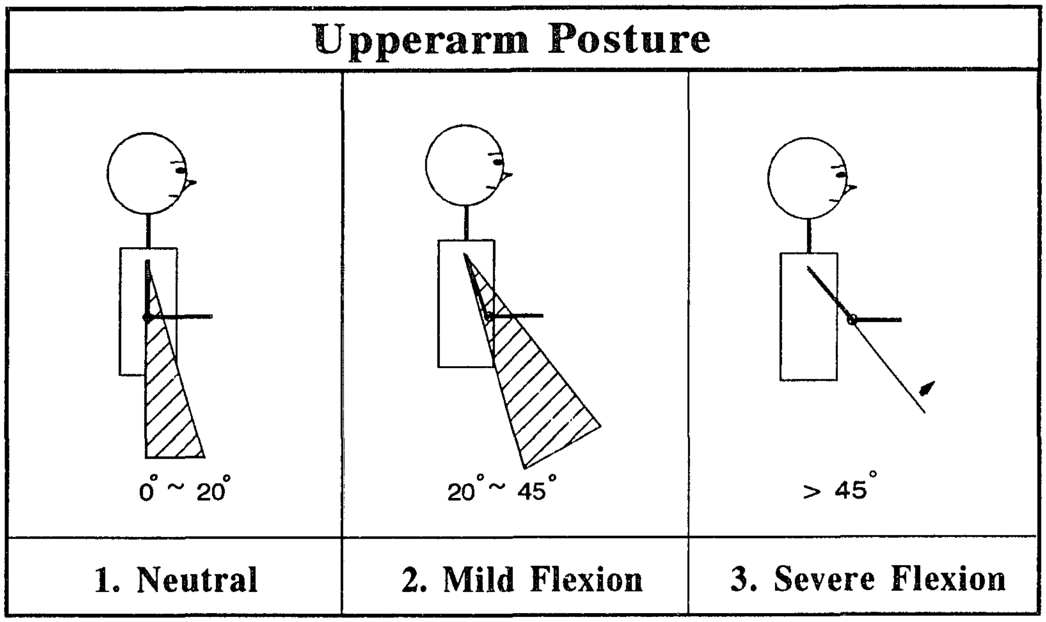


Figure 5.7 Upper arm posture

5.4.2.4 LOWER ARM POSTURE

The angle of lower arm posture is defined as the deviation from the upper arm. The ranges and scores for the lower arm posture are (ANSI/HFS 100-1988) (Figure 5.8):

- 1. Neutral: <= 90°;
- 2. Mild extension: 90° - 135°;
- 3. Mild flexion: 70° - 90°;
- 4. Severe extension or flexion: < 70° or > 135°.

5.4.2.5 WRIST POSTURE

Wrist posture was classified into the following two categories (McAtamney and Corlett, 1993) (Figure 5.9):

- 1. Neutral position: 0-15° mild extension
- 2. Extension: 15° or more extension

If the wrist is in either radial or ulna deviation then the posture score is increased by 1.

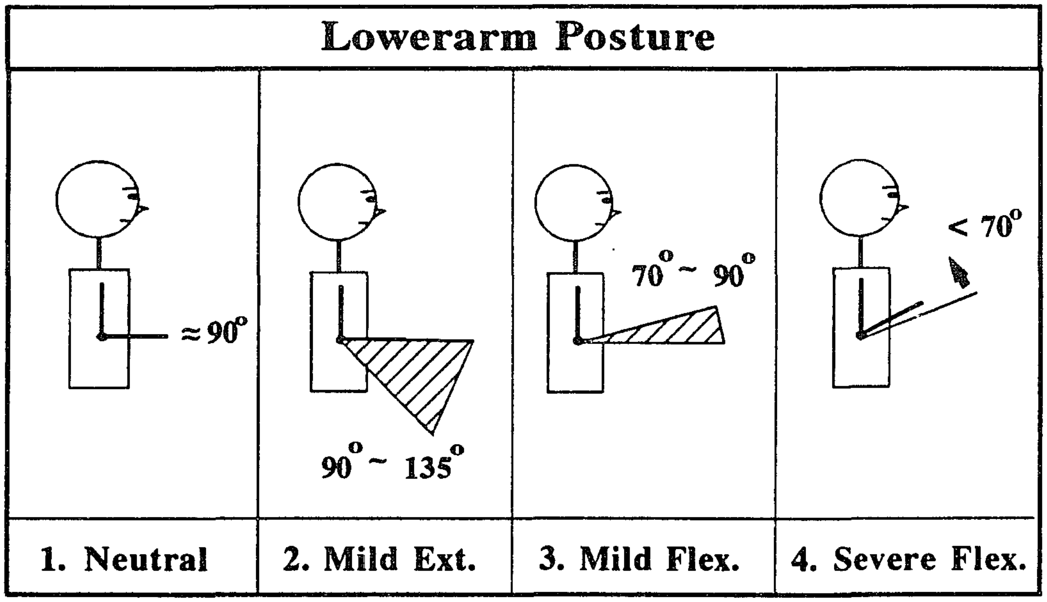


Figure 5.8 Lower arm posture

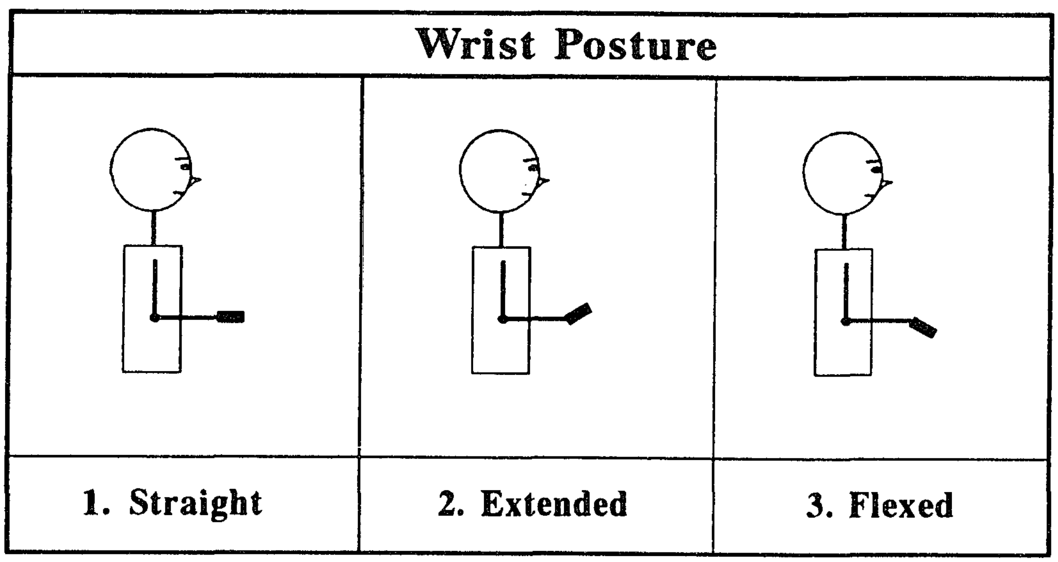


Figure 5.9 Wrist posture

5.4.2.6 LEG AND FOOT POSTURE

Proper support to the feet is important to the operator. The following categories were used to classify the leg and foot posture (McAtamney and Corlett, 1993) (Figure 5.10):

- 1. The legs and feet are well supported and in an evenly balanced posture;
- 2. The legs and feet are not well supported (inappropriate placement of the legs and feet such as crossing the legs or placing the feet on the chair support).

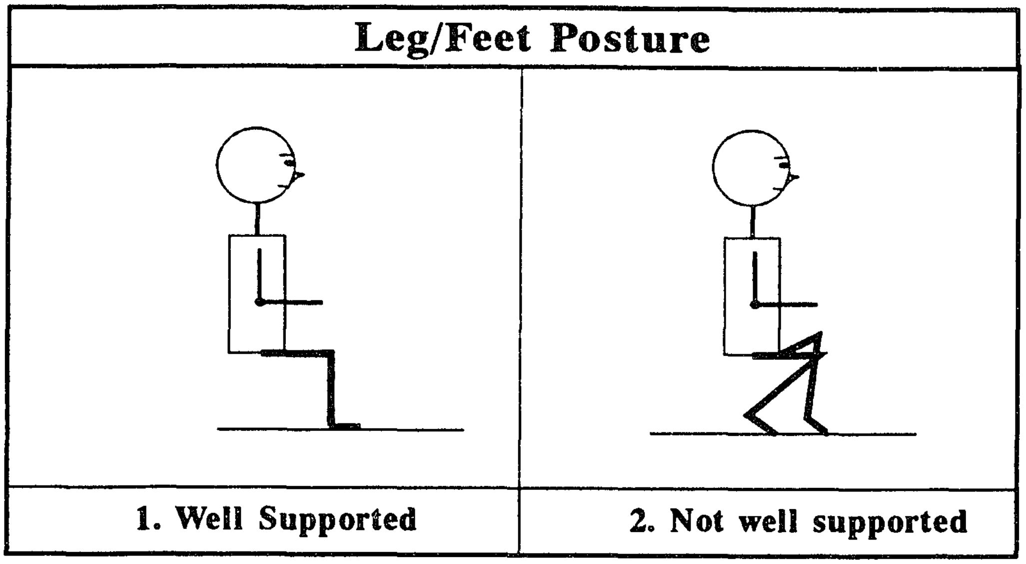


Figure 5.10 Leg/foot posture

A posture analysis worksheet was developed corresponding to the above posture scoring method (see Appendix D). The operator's working postures were videotaped at the workplace and analyzed in the laboratory.

5.5 DATA ANALYSIS METHODOLOGY

Data from questionnaire survey, measurements, and posture analysis were coded and then entered into the computer. A total 14,000 data were entered. A statistic software package SAS 6.07 on TSO of IBM 3090 mainframe was used for the data analysis. Data analysis procedure is summarized in Figure 5.

5.5.1 DESCRIPTIVE STATISTICS

Frequency analysis and contingency table were first used to examine the frequency distribution of the data. The variables which did not have much variation were taken out. The criteria used here was 20:80 for dichotomy data.

Data were plotted for the dependent variables against the independent variables to identify the dependencies.

5.5.2 UNIVARIATE ANALYSIS

Correlation analysis was used to examine the closeness of linear relationship between two variables. Pearson correlation was used for the numerical and interval data. Spearman correlation was used for the rank-order variables, such as the rating of physical symptoms. Analysis of variance (ANOVA) was used for examining the effect of the categorical variables on health symptom data. After above analysis, some variables were further taken out for the sake of simplicity. The multivariate analysis approach was then applied.

Multiple regression analysis was used for finding the most important variables (independent variables) for the health symptoms (dependent variables) and to quantifying the relationships. Factor analysis was used for some variable categories before the regression analysis. Factor scores were then used instead of the individual variables in the regression analysis.

5.5.3 MULTIVARIATE ANALYSIS

Factor analysis was used for identifying the underling factors of the same measures, for example, physical health symptoms. Factor scores of these variables were then output to regression analysis.

Multivariate analysis of variance (MANOVA) was used to examine the effect of a variable (categorical or ordinal) on a set of variables such as the health symptoms.

Canonical correlation is a technique for analyzing the relationship between two sets of variables. Each set can contain several variables. A SAS procedure, CANCORR, will serve for this purpose. Given two sets of variables, the CANCORR procedure finds a combination from each set, called a canonical variable, such that the correlation between the two canonical variables is maximized (SAS Institute Inc., 1989). Canonical correlation was used for examining the relationship between the variable categories in the research model.

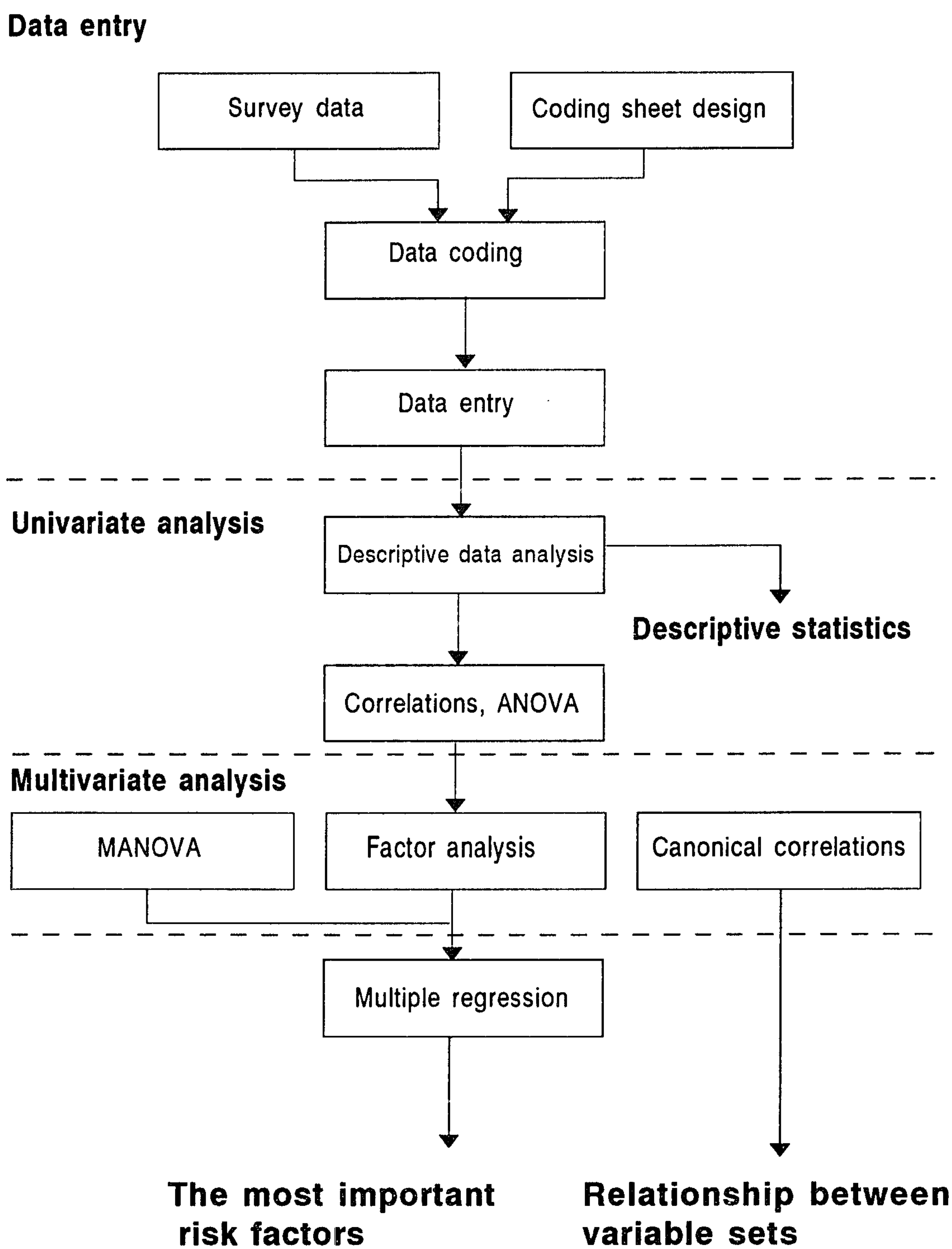


Figure 5.11 Data analysis procedure

CHAPTER 6

RESULTS

6.1 BACKGROUND INFORMATION

Ninety-three VDT users answered the questionnaire, among which 80 participated in workstation, environment, and anthropometric measurements, and 74 participated in video recording of working postures in the workplace. There were 88 valid respondents. Some questionnaire answers were considered invalid for the reasons of short employment length (less than three months), not full-time employees, or incomplete questionnaire answers.

6.1.1 SITE AND DEPARTMENT

Subjects came from two different sites, Our Lady of the Lake Hospital (OLOL) and Louisiana State University (LSU). The number of subjects in each department and site is listed in Table 6.1.

Seventy-two subjects (81.8%) were from OLOL. These operators worked intensively on the computer for data entry, information retrieval, word processing, and programming. Among the offices surveyed, two offices had very heavy computer users, Business Office and Accounting & Payroll Office. Operators in the Business Office worked on the medical records, payment collection from patients and interacted with the insurance company. They worked in one big office that was separated by dividers into three sections: Medicare, Collection, and Insurance. In addition to the computer, they spent a lot of time answering phone calls. Their work pace was basically controlled by phone calls and the noise level in the workplace was the highest when compared with the

Table 6.1 Sites and departments in VDT workstation survey

Site	Department	Number	Percent
OLOL		72	81.8
	• Business Office		
	- Medicare	11	
	- Collection	13	
	- Insurance	10	
	• Accounting and Payroll	17	
	• Other Offices		
	- Administration office	5	
	- Human resource	4	
	- Decision support group	3	
	- Quality services	2	
	- Nursing services	2	
	- Library	1	
	- Social services	1	
	- Elderly services	1	
	- Foundation	1	
LSU		16	18.2
	• Penington Biomedical Center	6	
	• IE Department	2	
	• Engineering Services	2	
	• Independent Study	2	
	• Deans Office	1	
	• Agriculture Lab	1	
	• Traffic Office	1	
	• Safety and Risk Management	1	
	Total:	88	100%

other departments surveyed. The type of computer most operators used was a terminal that was connected to a database system in the hospital. In the Accounting and Payroll Office which was another big office, most people worked with personal computers (PCs). They worked heavily with numerical data, either data entry or retrieval. In other offices of OLOL, VDT operators were more isolated than people in the Business Office and Accounting & Payroll Office. In Decision Support Group, all operators worked on programming. In other offices, most operators used the computer for word processing. Computer tables and adjustable computer chairs were used in all offices. The work schedule was eight hours per day with a 30-minute break for lunch, and two 15-minute coffee breaks with one in the morning and the other in the afternoon.

Sixteen subjects were from LSU which included professors, programmers, and secretary/clerical workers. Most operators in LSU performed word processing or programming tasks which were similar to the work performed by operators in the 'other office' category of OLOL. These computer users worked in many different offices and were more isolated (see Table 6.1).

6.1.2 USER CHARACTERISTICS

Subjects were all full-time employees. Table 6.2 shows the anthropometric data of the subjects. According to their job titles, subjects are classified into the following categories for their professions: (1) management, which includes various levels of supervisors and managers, (2) professionals, which include professors, specialists, and programmers who work more independently than other operators, (3) secretaries, which include secretaries and executive secretaries who perform a variety of tasks besides word processing, and (4) clerical workers, which includes data entry clerks and other clerks, who performed relative simple and repetitive tasks. Clerical workers including clerks and

Table 6.2 Anthropometric data from the subjects in the VDT workstation survey (sample size n=80)

Variable	Mean	Std. Dve	Range (cm)
Height	166.5	6.75	149.3 - 186.0
Eye height	116.0	4.38	107.0 - 128.5
Elbow height	67.4	3.64	57.5 - 76.0
Popliteal height	47.3	2.58	42.5 - 53.6

Table 6.3 User characteristics in VDT workstation survey (n=88)

Characteristics	Means	Standard Deviation	Ranges	Numbers (Percent)
Gender Female Male				 77 (87.5%) 11 (12.5%)
Age	38.3 yrs	11.08	21-63 yrs	
Length of time at present job	55 mths	74.73	3 mths - 36 yrs	
VDT work history	85 mths	50.38	7 mths - 21 yrs	
Professions Management Professionals Clerical worker				 7 (8%) 20 (22.7%) 61 (69.4%)
Type of eye wear None Contact lenses Regular glasses Bifocals Trifocals Other				 21 (23.9%) 22 (25.0%) 21 (23.9%) 17 (19.3%) 4 (4.5%) 3 (3.45)
Eye wear designed for VDT use (n=67) Yes No				 20.9% 79.1%
Regular eye exam. Yes No				 75% 25%

secretaries (69.4%) were the major part of the subjects (Table 6.3). The data of gender, age, length of employment, and VDT work experiences are also shown in Table 6.2. It shows that most subjects are females (87.5%). Eye wear information shows that 76.1% of the operators used various eye wears. Among the subjects who used eye wears (n=67), 20.9% used the type of eye wear that was designed for computer use.

6.1.3 TASK CHARACTERISTICS

Task characteristics is shown on Table 6.4. The average working time per day was 8.4 hours among the VDT operators surveyed, of which 25.3% worked over time from 0.5 hour to 4 hours per day. Subjects were all daily computer users. The average time of computer use was between 4-6 hours per day. Sixty-five percent (65%) of operators used the computer over 4 hours per day, nineteen (19%) of operators used computer less than 4 hours per day, and for the other operators (16%), the time spent using the computer varied greatly. It is seen that most operators performed more than one task with the computer. It also shows that most VDT operators (97.3%) did not use a mouse for their tasks. The computers used by VDT operators were IBM personal computers or compatible (PCs) (55%) and mainframe terminals (45%). The major software used were a database system on the mainframe, a database system on PCs, a Lotus 1-2-3 spread sheet, Word Perfect, and Harvard Graphics/AutoCAD.

6.1.3.1 TYPES OF VDT TASK

The major tasks performed by VDT operators were data entry, information retrieval/interactive work, word processing, programming, and drawing/computer aided design (CAD) (Table 6.4).

Since most operators performed more than one type of task with VDTs, tasks are further classified into the following two categories (Table 6.5): (1) single task, and (2) multiple task. The first category "Single task" means that operators perform only one type of task, either data entry, or word processing, or interactive work/information retrieval. 44.3% of operators belonged to this category. The second category "Multiple task" means that the operators performed a combination of more than one type of VDT task. 55.7% of operators belonged to this category. The single task is then further divided into 3 categories: (1) word processing, which includes the task of typing reports, letters, and memos, (2) data entry, which includes the task of entering numerical data, (3) interactive work or information retrieval, which includes interactive task, information retrieval, programming, and drawing/CAD. The Multiple tasks are also divided into the following four categories: (4) word processing and interactive work/information

Table 6.4 Task characteristics

Characteristics	Means, Standard Deviation, Percent
Working hours/day	Mean: 8.4 hours/day Standard Dev.: 0.83 Range: 8-12 hours
Task	Data entry: 64.8% Information retrieval /interactive work: 61.4% Word processing: 47.7% Programming: 3.4% Drawing/CAD: 4.5%
Hours of using VDT /day	0-1 hour: 1.1% 1-2 hours: 2.3% 2-4 hours: 15.9% 4-6 hours: 22.7% >6 hours: 42.0% Varies greatly: 15.9%
Time of using VDT continuously	0-1 hour: 26.1% 1-2 hours: 12.5% 2-4 hours: 28.4% Varies greatly: 33.0%
Use of mouse	Yes: 20.7% No: 79.3%

retrieval, (5) data entry and word processing, (6) data entry and interactive work/ information retrieval, and (7) multiple task. Since very few subjects belonged to the task category of "programming" (3 subjects, 3.4%) and "drawing/CAD" (4 subjects, 4.5%) and these subjects, all except for one, performed more than one task, they were classified into multiple task category (tasks 4, 5, 6, or 7) according to their other tasks. The subject who only worked on "drawing/CAD" was classified into Task 3, interactive work/information retrieval. The classified task categories, frequencies, and percentages are listed in Table 5.4. It is noticed that Tasks 1, 4, and 5 all involve "word processing", Tasks 2, 5, and 6 all involve "data entry", and Tasks 3, 4, and 6 all involve "interactive work/information retrieval".

Table 6.5 Types of VDT task and frequencies

Task Category		Frequency	Percent
Single tasks	1. Word processing	9	10.2%
	2. Data entry	13	14.8%
	3. Interactive work/Information retrieval	17	19.3%
Multiple tasks	4. Word processing and interactive work	5	5.7%
	5. Data entry and word processing	11	12.5%
	6. Data entry and interactive work	16	18.2%
	7. Multiple task (three types of task)	17	19.3%
Total		88	100%

6.2. THE EXTENT AND PATTERN OF HEALTH COMPLAINTS

6.2.1 DESCRIPTIVE DATA

Three types of physical complaints were collected: musculoskeletal symptoms (neck, shoulders, upper back, elbows, wrists, lower back, hips/thighs, knees, and ankles), visual symptoms (tearing eyes, dry eyes, blurred vision, burning eyes, and tired eyes), and general physical symptoms (headache, stomach ache, and ringing ears). In addition, psychological complaints (extreme fatigue, anxiety, and depression) were also studied.

The following ordinal scale was provided to the subjects for checking the extent of possible symptoms:1 for "Never"; 2 for "Less than once a week"; 3 for "Once a week"; 4 for "More than once a week"; and 5 for Daily".

The extent of health complaints is shown in Figure 6.1, Figure 6.2., Figure 6.3, and Figure 6.4. for musculoskeletal symptoms, visual symptoms, general physical symptoms, and psychological complaints, respectively. It is shown that over 50% of the operators experienced the following symptoms: tired eyes (86.3), extreme fatigue (81.8%), headache (78%), anxiety (63.7%), neck pain (62.5%), shoulder pain (62%), and tearing eyes (60.2%). The top complaints that operators experienced daily were: tired eyes (21.6), shoulder pain (17.2%), neck pain (13.6%), anxiety (11.4%) and headache(8%).

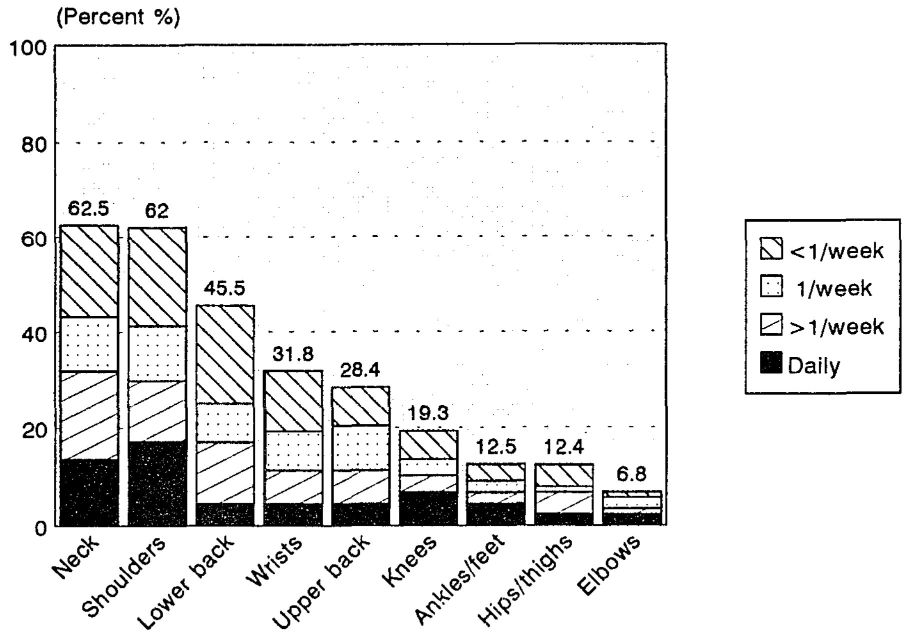


Figure 6.1 The extent of musculoskeletal symptoms

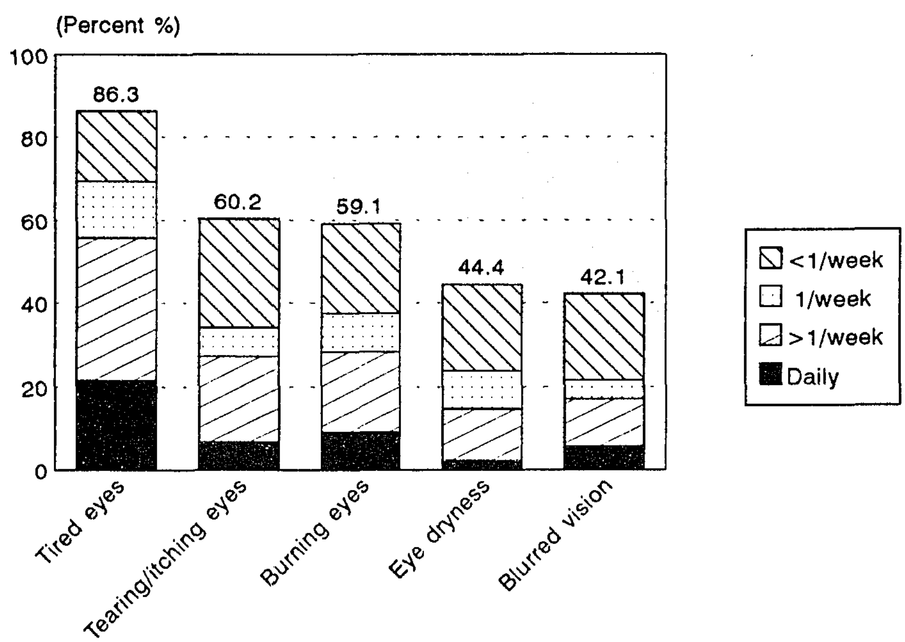


Figure 6.2 The extent of visual symptoms

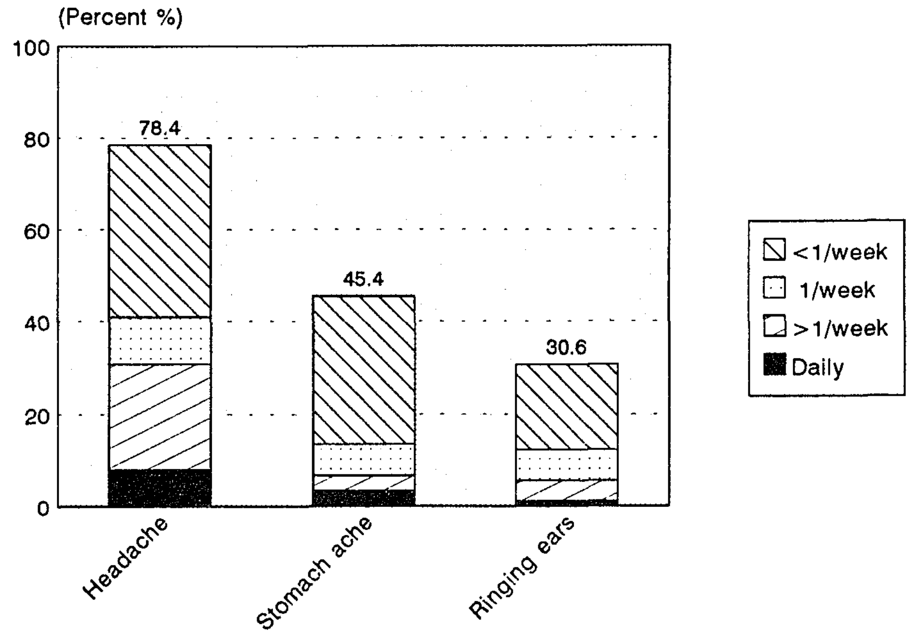


Figure 6.3 The extent of general symptoms

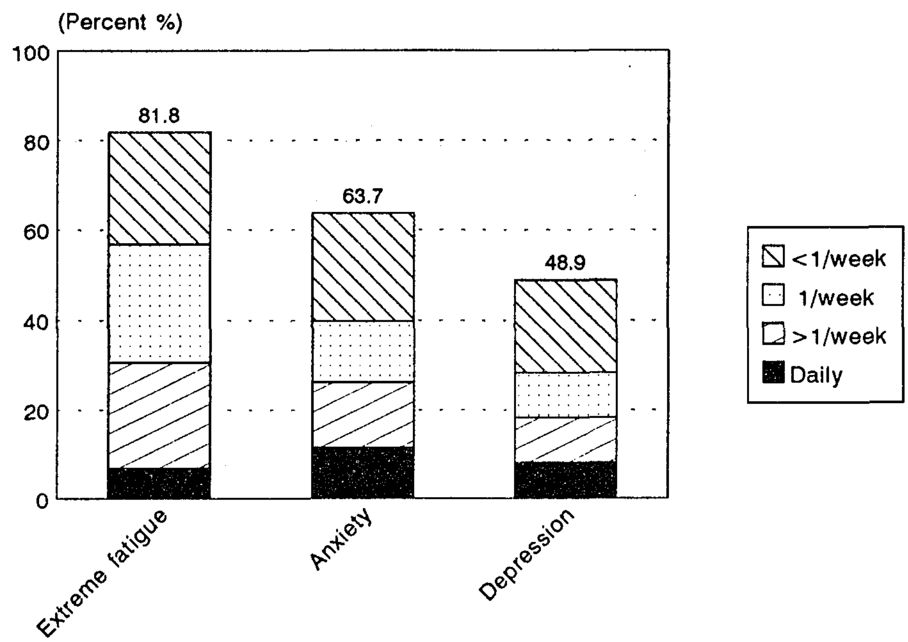


Figure 6.4 The extent of psychological symptoms

6.2.2 CORRELATION ANALYSIS

Table 6.6 shows the correlations between the health complaints. Spearman correlation which is appropriate for ordinal variables was used for the analysis because all variables of the health symptoms can be considered as ordinal variables.

The correlation matrix shows that the physical complaints of musculoskeletal symptoms for upper body parts (above hips) have almost no correlation with the physical complaints for the lower extremity (hips/thighs, knees, and ankles/feet). The exception is a significant correlation between hips/thighs and lower back ($r=0.21$, $p<0.05$) which might be considered as a link between upper body and lower extremities. On the other hand, the upper body segments above and below hips/thighs both have significant correlations within their body parts. For the body segments, complaints of neck, shoulder, upper back, and wrists which are all above the lower back have significant correlations. Lower back complaints have no correlation with arm complaints (elbows and wrists), but have significant correlation with neck and shoulder complaints.

Visual symptom variables have significant correlations within variables. They have significant correlation with musculoskeletal symptoms of neck, shoulders, upper back, and lower back, but not elbows and wrists. Visual symptoms have almost no correlation with musculoskeletal symptoms of the lower extremities.

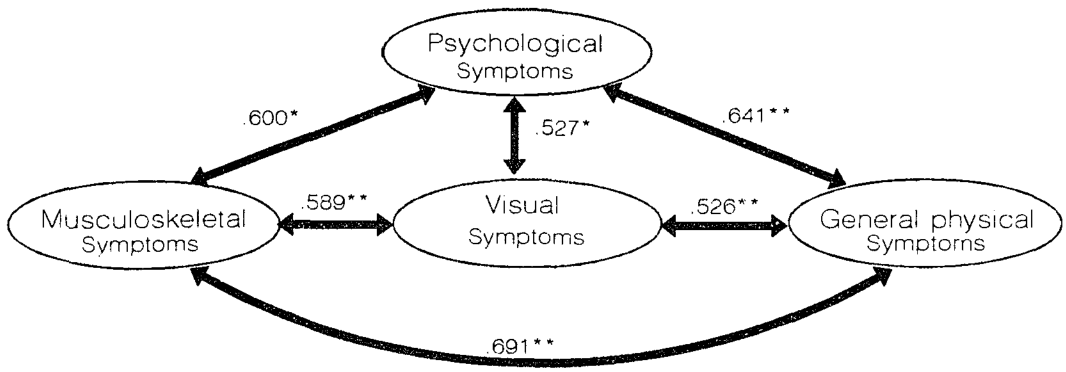
General physical symptom variables have significant correlations with each other. They also have significant correlations with visual symptoms, and musculoskeletal symptoms of body part (neck, shoulders, upper back, and lower back). They have almost no correlation with complaints at upper and lower extremities.

Psychological complaint variables have significant correlations with each other. They significantly correlate with all variables of general physical symptoms. Like general physical symptom variables, psychological complaints also have significant correlations

Table 6.6 Spearman correlation coefficients among health complaints (sample size n=88)

	Variables	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
1	Neck																			
2	Shoulders	.64***																		
3	Upper back	.52***	.41***																	
4	Elbows	.14	.14	.21*																
5	Wrists	.24*	.20	.33**	.30**															
6	Lower back	.34***	.30**	.07	.05	.04														
7	Hip/ thighs	-.03	.03	.05	.14	-.07	.22*													
8	Knees	-.18	-.02	-.04	.07	.01	-.11	.43***												
9	Ankles /feet	-.01	.08	.05	.02	.10	.14	.29**	.30**											
10	Tearing eyes	.13	.26*	.13	.16	.10	.22*	.11	.27***	.19										
11	Dry eyes	.17	.20	.17	.14	.01	-.01	.05	.11	.26*	.25*									
12	Blurred vision	.19	.05	.25*	.11	.21*	-.05	-.08	.00	.05	.25*	.34***								
13	Burning eyes	.36***	.40***	.27**	.16	.15	.25*	.02	-.15	.05	.61***	.15	.25**							
14	Tired eyes	.32**	.36***	.16	.02	.00	.27**	.11	.00	-.03	.37***	.38**	.28**	.53***						
15	Headaches	.41***	.39***	.26*	.03	.12	.27*	-.01	.02	.10	.17	.30**	.12	.10	.39***					
16	Stomach ache	.43***	.36***	.33**	.26*	.19	.23*	.09	.18	.22*	.42***	.36***	.25*	.24*	.16	.35***				
17	Ringing ears	.24*	.15	.39***	.19	.03	.21*	.18	.15	.06	.13	.16	.21*	.00	.24*	.25*	.32**			
18	Extreme fatigue	.51***	.30**	.19	.08	.01	.33**	.19	.08	.13	.16	.30**	.20*	.24*	.47***	.42***	.46***	.38***		
19	Anxiety	.25*	.08	.20	-.02	.00	.09	.05	.20	.11	.13	.24*	.19	-.01	.19	.31**	.30**	.31**	.48***	
20	Depression	.29**	.18	.24**	-.04	.05	.06	.06	.18	.08	.19	.26*	.21*	.12	.30***	.35**	.33**	.17	.35***	.72***

*p<0.05, **p<0.01, ***p<0.001



* p<0.01, ** p<0.001

Figure 6.5 Canonical correlations of four categories of health symptom variables

with visual symptom variables and musculoskeletal symptom variables of body part (neck, shoulders, upper back, and lower back) but not upper and lower extremities.

In summary, significant correlations exist among the variables of musculoskeletal, visual, general physical, and psychological symptoms. Very few variables are correlated with musculoskeletal symptom variables of the lower extremity (hips/thighs, knees, and ankle/feet) and elbow. This may be because of the low responses for these variables (6.8% for elbows, 12.4% for hips/thighs, 12.5% for angles/feet, and 19.3% for knees) in this small sample (n=88) (see Figure 6.1).

In order to further examine the relationship between the four categories of variables, i.e., psychological, musculoskeletal, visual, and general physical symptoms, canonical correlation which is used for examining the correlation between two sets of variables was used. Figure 6.5 shows the results of the canonical correlation of each two sets of health symptom variables with the results of testing the null hypothesis that the canonical correlation is zero. It can be seen that all of the largest canonical correlations between each two sets of variables are significant at $p=0.01$ level. It can be concluded that the four categories of health symptom variables are significantly correlated.

6.2.3 FACTOR ANALYSIS

Factor analysis was used to investigate the underlying factors among the health complaints. Principal component factor analysis, principal factor analysis, iterated principal factor analysis, and maximum-likelihood factor analysis were used. Varimax, equamax, and quartimax were used for orthogonal factor rotation in conjunction with the factor analysis. Three-, four-, and five-factor pattern solutions were tried. A scree plot was also used to help determine the number of factors.

The results of principal component factor analysis with varimax rotation were finally used and four factors were identified based on (1) reasonableness of the results and (2) the proportion of sample variance explained by the factors. Table 6.6 shows the factor loadings of variables and their communalities. The cumulative proportion of total sample variance explained by the 4 factors is 62 percent.

The first factor might be called "stress" factor. Six variables are included in this factor: fatigue (UFE), anxiety (ANX), depression (DEP), headache (HDE), stomach discomfort (SDE), and ringing ears (ERE). These variables are "psychological complaints" and "general physical symptoms." This might imply that all above symptoms (psychological and general physical symptoms) are related to stress. It is seen, that all general physical symptoms have relatively low factor loadings when compared with that of psychological stress. The second factor might be called "vision" factor. Five visual symptom variables are included in this factor: tearing/itching eyes (TIE), dry eyes (DRE), burning eyes (BEE), tired eye (TRE), and blurred vision (BVE). The third factor might be called "general musculoskeletal stress" factor. The variable "lower back (LBE)" has the highest loading in this factor, and then the variables of neck (NCE) and shoulder (SHE). Fatigue (UFE) and headache (HDE) also have relatively high loadings in this factor and should be included. So this factor includes a mix of musculoskeletal and fatigue symptoms. This might suggest that these symptoms are the musculoskeletal symptoms related to general fatigue. The fourth factor might be called "upper body" factor. It includes the variables of body segments which are above the lower back, i.e. neck (NCE), shoulders (SHE), wrists (WHE), and upper back (UBE).

Table 6.7 also shows the communalities for all variables. The *i*th communality is the portion of the variance of the *i*th variable contributed by the m common factors (Johnson and Wichern, 1992). It may be seen that communalities of most variables are over 0.55, i.e., over 55% of variance of these variables can be explained by the 4 factors, except the variables HDE (headache), SDE (stomach ache), ERE (ringing ears) and DRE (dry eyes).

To summarize, the health complaints from VDT use mainly presents the following pattern:

- Stress related complaints. This category includes variables of psychological stress, i.e., extreme fatigue, anxiety, and depression, and general physical symptoms, i.e., headaches, stomach ache, and ringing ears.

- Visual symptoms. Visual symptom category includes the variables of the symptoms of visual and ocular discomfort, i.e., tearing/itching eyes, dried eyes, burning eyes, tired eyes, and blurred vision.

- General musculoskeletal stress symptoms. This category includes the musculoskeletal symptoms of lower back, neck, shoulders, fatigue, and headache.

- Upper body musculoskeletal symptoms. This category includes the symptoms of wrists, shoulders, upper back, and neck which are all geographically above the lower back of the body.

In the above factor analysis and the following analysis, some variables were deleted which included variables of the lower extremities (hips/thighs, knees, and ankle/feet) and elbows because of the low response rate (less than 20%).

Table 6.7. Rotated factor pattern for health complaints
(principal component factor analysis + varimax factor rotation)

	Estimated factor loadings				
	F1	F2	F3	F4	Communalities
NCE			.573	.549	.737
SHE			.620	.499	.681
UBE				.758	.692
LBE			.766		.621
WHE				.736	.559
TIE		.783			.634
DRE		.458			.411
BVE		.528			.561
BEE		.775			.757
TRE		.648			.595
UFE	.609		.435		.607
ANX	.855				.731
DEP	.769				.616
HDE	.515		.446		.485
SDE	.422				.435
ERE	.479				.288

Note:

NCE-neck, SHE-shoulders, UBE-Upper back, LBE-lower back, WHE-wrists, TIE-tearing eyes, DRE-dry eyes, BVE-blurred vision, BEE-burning eyes, TRE-tired eyes, UFE-extreme fatigue, ANX-anxiety, DEP-depression, HDE-headache, SDE-stomach ache, ERE-ringing ears.

6.3 WORKING POSTURES AND MUSCULOSKELETAL SYMPTOMS

Operators' working postures were analyzed according to the posture scoring system developed in Chapter 4. According to this posture analysis method, the body is divided into six parts and a score which is associated with the degree of risk to the musculoskeletal disorder is assigned to each predefined posture. The six parts of body segment are: head/neck, torso, upper arms, lower arms, wrists and legs/feet.

Table 6.8 shows the percentage of data in each posture category. It is seen that although over 50% operators had neutral head/neck and trunk posture in terms of degrees of flexion, over 50% operators had twisted posture or movement.

Table 6.9 shows the correlation matrix of the posture scores and musculoskeletal complaints. In order to eliminate the possible effect of past medical condition on the musculoskeletal complaints, the answers from the survey were deleted when subjects indicated that symptoms were related to past accidents. This resulted in 52 valid observations. It shows that head/neck posture is only related to upper back complaints; trunk posture is related to the complaints at the body region (neck, shoulder, upper back, and lower back); upper arm posture is related to the complaints at neck, shoulders and lower back; wrist posture is related to the complaints at neck, upper back, and wrists. Lower arm posture and legs/feet posture are not related to any musculoskeletal complaints at the significance level of 0.05.

Figure 6.6 shows the results of canonical correlation analysis between the categories of posture, psychological stress, musculoskeletal complaints, vision complaints, and general physical symptoms. It is seen that the correlation between posture, and musculoskeletal symptoms, visual symptoms, general physical symptoms, and psychological stress are significant.

6.4 WORKSTATION DESIGN

6.4.1 SUBJECTIVE AND OBJECTIVE EVALUATIONS

The following items were evaluated by both subjective and objective measurements: screen glare, screen position, keyboard position, and chair comfort. In order to determine which type of measurement should be used for testing the proposed

Table 6.8 Descriptive data of posture analysis (n=74)

No.	Body Parts	Score Range	Percent
1	Head/neck	1. 10° extension to 20° flexion 2. 20 or more flexion 3. 10° or more extension Posture or movement twisted? 0. No 1. Yes	51.4% 42.9% 5.7% 28.6% 71.4%
2	Trunk	1. 20° extension to 20° flexion 2. 20° or more flexion Posture or movement is twisted? 0. No 1. Yes Movements have been observed? 0. Yes 1. No Lower back is supported? 0. Yes 1. No	80.0% 20.0% 48.6% 51.4% 84.3% 15.7% 87.1% 12.9%
3	Upper arms	1. 0-20° flexion 2. 20-45° flexion 3. 45° or more flexion Shoulder is elevated? 0. No 1. Yes Upper arm is abducted? 0. No 1. Yes The weight of arm is supported? -1. Yes 0. No	52.9% 44.3% 2.9% 81.4% 18.6% 60.0% 40.0% 41.4% 58.6%
4	Lower arms	1. ≈90° flexion 2. 90-135° flexion 3. 70-90° flexion 2. < 70° flexion	55.7% 12.9% 28.6% 2.9%
5	Wrists	1. 0-15° extension 2. 15° or more extension Wrists are rested on the edge of the keyboard or wrist rest during typing? 0. No 1. Yes	54.3% 45.7% 51.4% 48.6%
6	Legs/feet	Legs/feet are well supported? 1. Yes 2. No	77.0% 23.0%

Table 6.9 Spearman correlation coefficients of posture scores and musculoskeletal complaints (n=52)

	Posture					
Complaints	Head /neck	Trunk	Upper arm	Lower arm	Wrists	Legs /feet
Neck	.15	.33**	.33*	.11	.27*	.21
Shoulders	.00	.31*	.33*	.16	.22	.26
Upper back	.36**	.28*	.20	.20	.47**	-.02
Lower back	.06	.37**	.30*	-.02	.12	-.06
Wrists	.05	-.15	.11	.01	.32*	-.07

Note: * p<0.05, ** p<0.01

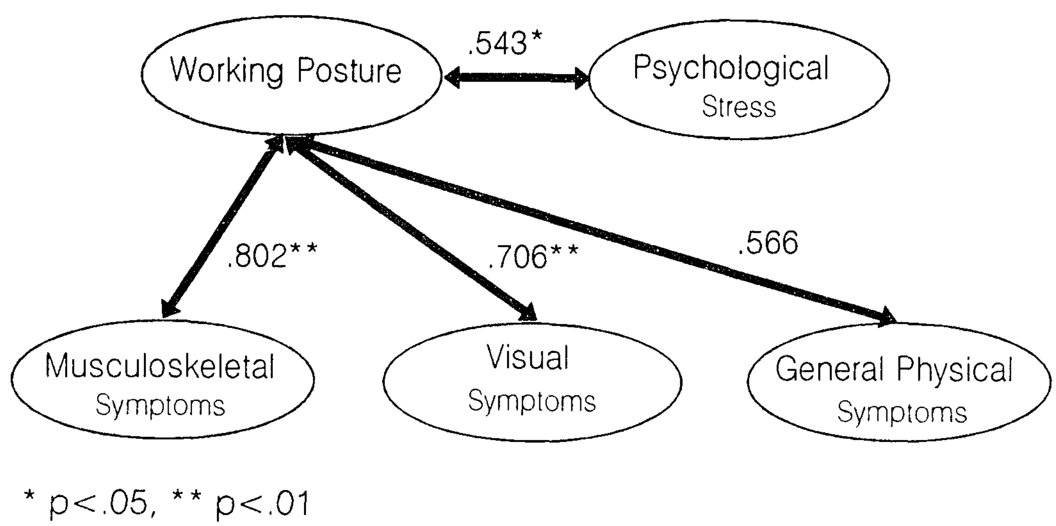


Figure 6.6 Canonical correlation between working posture and health symptoms

research model, the relationship between the objective and subjective measurement was analyzed. The hypothesis was that objective and subjective measurements were significantly correlated. The basic methods used here was Pearson correlation analysis and canonical correlation analysis which is a technique for analyzing the relationship between two sets of variables. The relationship between objective and subjective measurement for each workstation variable was analyzed first. Two-dimensional bar-charts and three-dimensional surface charts were also used to help interpret the results.

6.4.1.1 SCREEN GLARE

Three variables from the research by Schleifer and his colleagues (Schleifer et al., 1990) were used for the objective evaluation of the screen glare: (1) presence/absence of screen glare (SGL, 0=absence, 1=presence); (2) proportion of the display affected by screen reflections (SGP, 1=0%-25%, 2=26%-50%, 3=51-75%, 4=76-100%), and (3) degree of image visibility loss due to screen glare (SGI, 1=None, 2=Slight, 3=Moderate, 4=Severe). The objective evaluation was done by the researcher at the workplace. There is only one variable for the subjective evaluation of screen glare, the degree of screen glare (SCG).

Canonical correlation is used to test the relationship between the objective evaluation (SGL, SGP, SGI) and subjective evaluation (SCG) of screen glare. Pearson correlations between the objective and subjective evaluation variables are shown in Table 6.10. It shows that the correlations between the objective and subjective measurement variables are moderate, the largest being 0.5023 between SGI and SCG; There are larger within-set correlations: 0.7467 between SGL and SGI, 0.5383 between SGI and SGP, and 0.4651 between SGL and SGP. The canonical correlation is 0.5185. The probability level for the null hypothesis that all the canonical correlations are 0 in the population is 0.0001, so conclusion can be made that the correlation between objective and subjective evaluation of screen glare is significant.

Table 6.10 Correlations between objective and subjective measurement of screen glare

Objective Measurement	Subjective Measurement
	SCG
SGL	0.3126*
SGP	0.3318*
SGI	0.5023**

Note: * $p<0.01$, ** $p<0.005$

The canonical redundancy analysis shows that the canonical variables are not a good overall predictor of the opposite set of variables, the proportion of variance explained being 0.2689 and 0.1534. This means if the set of objective measurements (SGL, SGP, and SGI) is used to predict the subjective evaluation of screen glare, the proportion of variance explained by this prediction is 27%. On the other hand, if the subjective evaluation of screen glare is used to predict the objective measurements, the proportion explained by this prediction is only 15%.

The canonical variable for the objective measurement is a weighted difference of SGI (1.0914), SGP (0.2031), and SGL(0.3107), with more emphasis on SGI. This may imply that people rated the degree of screen glare relying more on the degree of image loss instead of the proportion of screen affected by the glare. The relationship among, the variables SCG (subjective rating of screen glare), SGI (image loss), and SGP (proportion affected) are drawn on a three-dimension space (Figure 6.7).

6.4.1.2 SCREEN POSITION

Two objective measurements for screen positions were used, (1) the screen position (SPTO) and (2) screen height (center of screen to floor) (MVH). Two subjective measurements were used, (1) comfort with the screen position (SCP) and (2) comfort with screen height (SCH).

Screen position was classified according to its relative position to the user, Front and Side. With the position of Front, the screen is placed directly in front of the user and

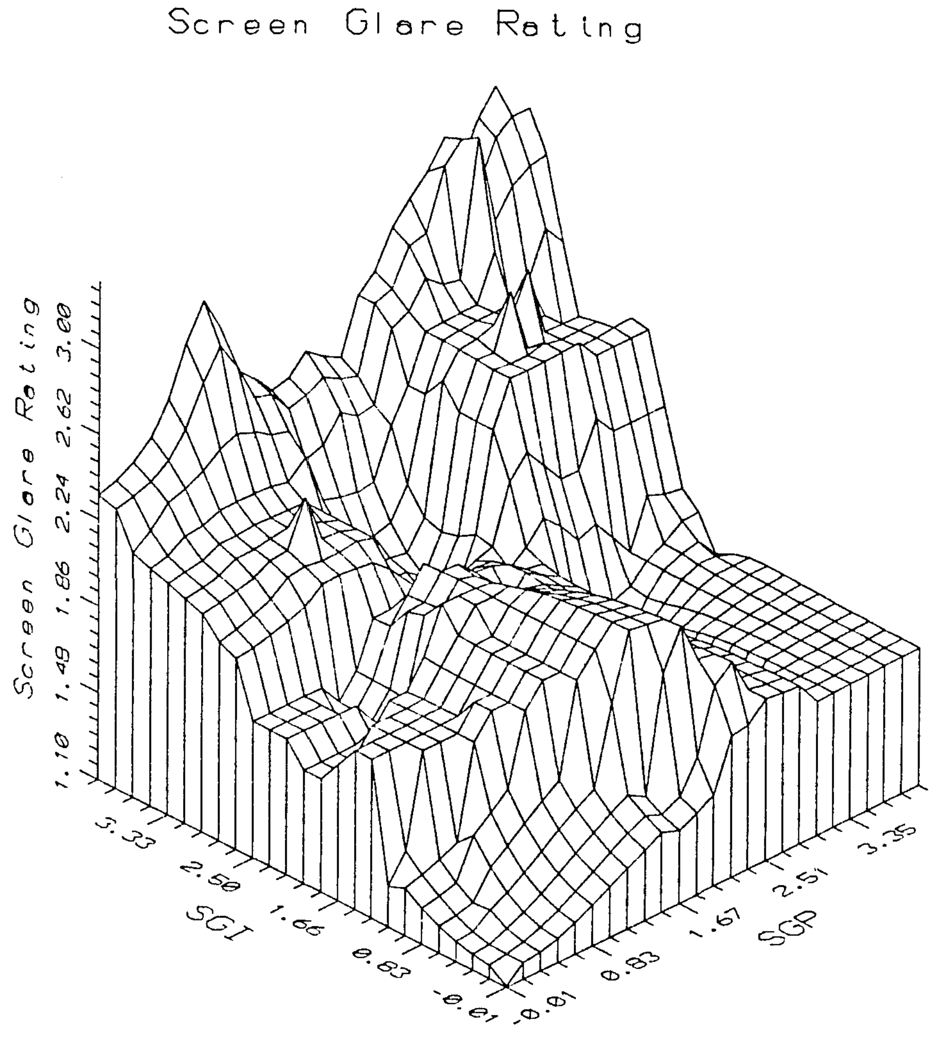


Figure 6.7 Objective and subjective evaluation of screen glare

the keyboard, and user can view the screen without twisting when working with the keyboard. With the Side position, the operator has to twist the neck or body to view the screen while working with the keyboard. It was assumed that the operator should feel more comfortable with Front position compared with the Side position.

Literature indicates that the top of screen should be the same as the eye height (ANSI/HFS 100-1988). Eye height was measured and the difference between the distance from the top of screen to floor and eye height was calculated (DIFF_V_E).

Figure 6.8 shows the subjective evaluation of the screen position for the two types of screen position. It shows that the percentage of operators who rated the screen position "comfortable" decreases from 72.5% with Front screen position to 58.6% with the Side position; the percentage of operators who rated the screen position 'slightly uncomfortable' increased from 17.6% to 31%, however, the percentage of operators who rated the screen position "moderate uncomfortable" decreases from 9.8% with Front position to 3% with Side position. However, analysis of variance (ANOVA) and correlation analysis indicates that there is no significant difference between the subjective ratings in terms of the objectively defined screen position.

Correlation analysis was also applied to the difference between the screen height (from the top of screen to floor) and the eye height. However, no significant correlation was found.

6.4.1.3 KEYBOARD POSITION

Two objective measurements were used for evaluating the keyboard position: (1) keyboard position (KBPO), and (2) relative keyboard height, which was the difference between keyboard height and elbow (DIFF_K_L). Two subjective measurements were used: (1) comfort with keyboard position (KBPS), and (2) comfort with keyboard height (KBHS).

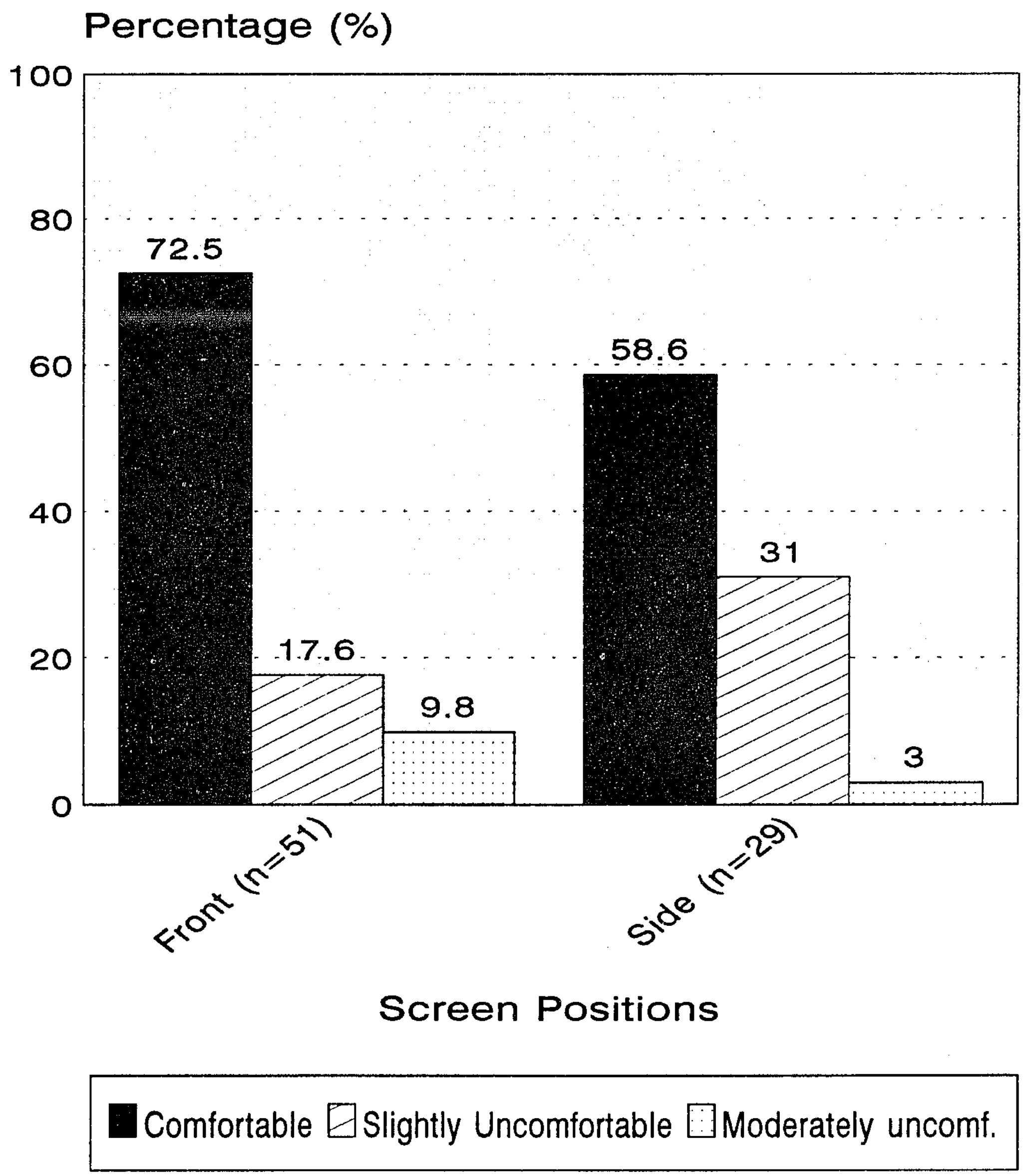


Figure 6.8 Subjective ratings and screen positions

The following keyboard positions have been found in the survey (Figure 6.9): (1) Front_I, (2) Front_II, (3) Front_III, and (4) Side.

(1) Front_I: The keyboard is positioned in front of the user and at the edge of the table. Some keyboard is positioned in a keyboard drawer. The operator types either with or without a wrist rest symmetrically (without twisting). (2) Front_II: The keyboard is placed across the edges of the working table. The operator types symmetrically with the elbows supported by the edges of the two working tables and with an abduction of upper arms. (3) Front_III: The keyboard is placed in the middle of the working table. The operator types with both elbows supported by the table and have wide opened upper arms. Sometimes, the operator tilt the keyboard to an angle. The VDT is usually placed at the left or right side of the table. (4) Side: The keyboard is positioned on the table tilted at an angle. This position is usually for matching the VDT position which is placed at left or right side of the table. In order to view the screen, the operator has to face the table with twisted body, and usually only one elbow is supported by the table.

It is found that 55% of operators rated their keyboard position 'slightly uncomfortable', 'moderately uncomfortable', or 'uncomfortable'. To further examine the subjective ratings and the keyboard positions, the ratings for different keyboard positions are shown in Figure 6.10. It shows that the percentage of operators who rated the keyboard 'comfortable' decreases from 59.2% with Front_I to 25% with Front_II, 20% with Front_III, and 16.7% with Side position. The percentage of operators who rated the keyboard 'slightly uncomfortable' jumped from 28.6% at Front_I to 60% with Front_II. The percentage of operators who rated the keyboard 'moderately uncomfortable' or 'uncomfortable' also increases from 12.2% with Front_I, to 33.3% with Side position. The mean ratings for different keyboard position is shown in Figure 6.11. Analysis of variance was applied and the result is marginal ($F=2.73$, $p<.05$).

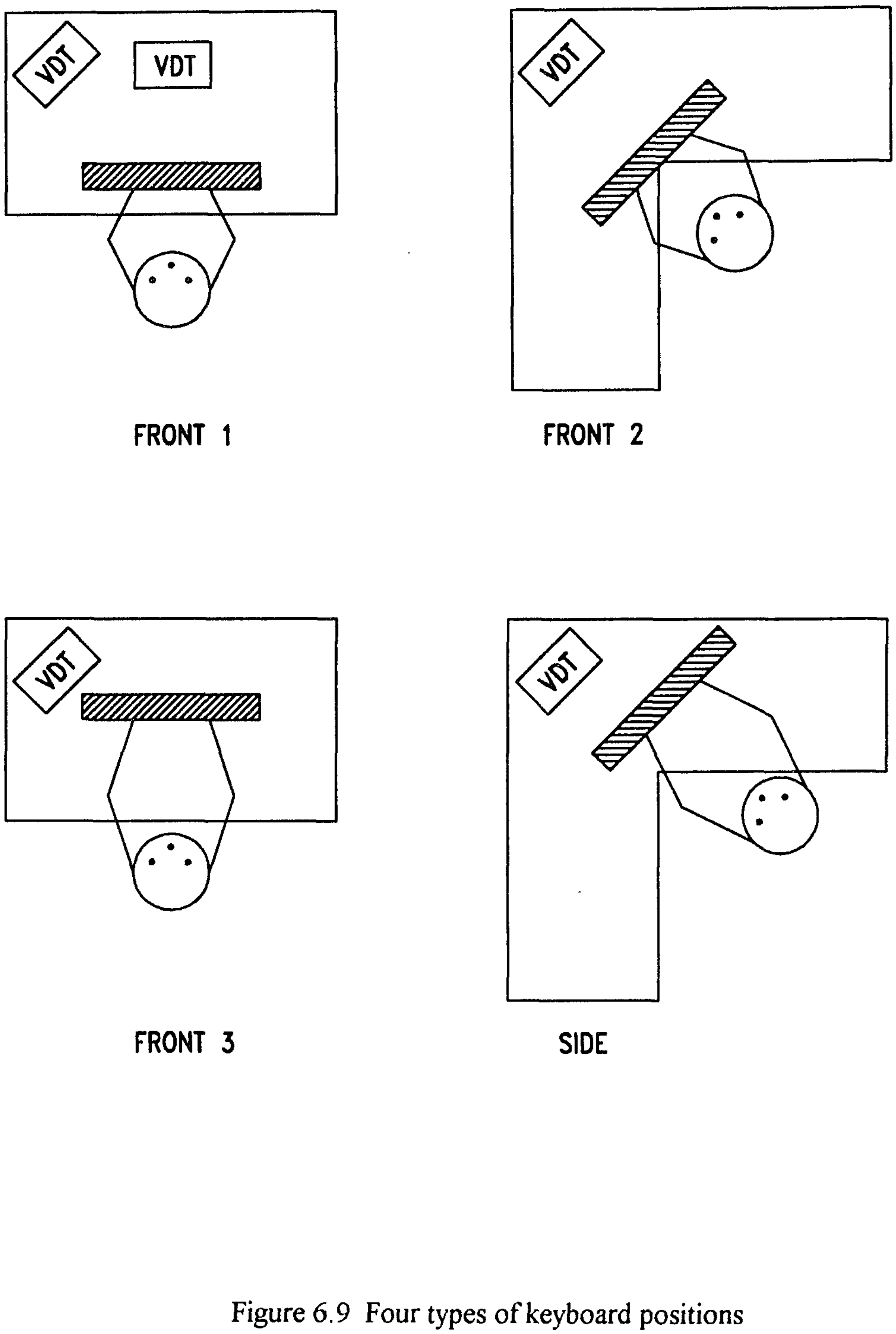


Figure 6.9 Four types of keyboard positions

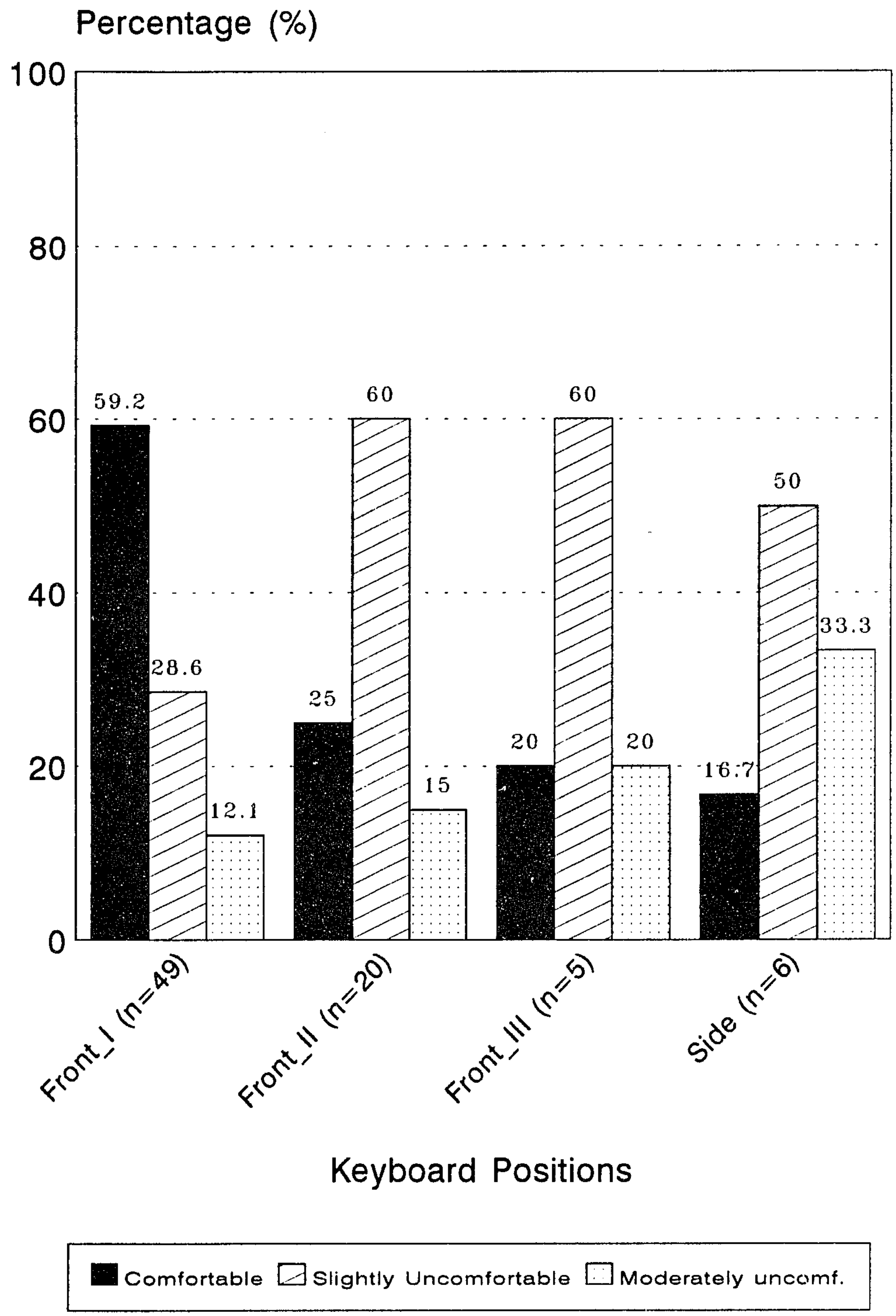


Figure 6.10 Subjective ratings and keyboard positions

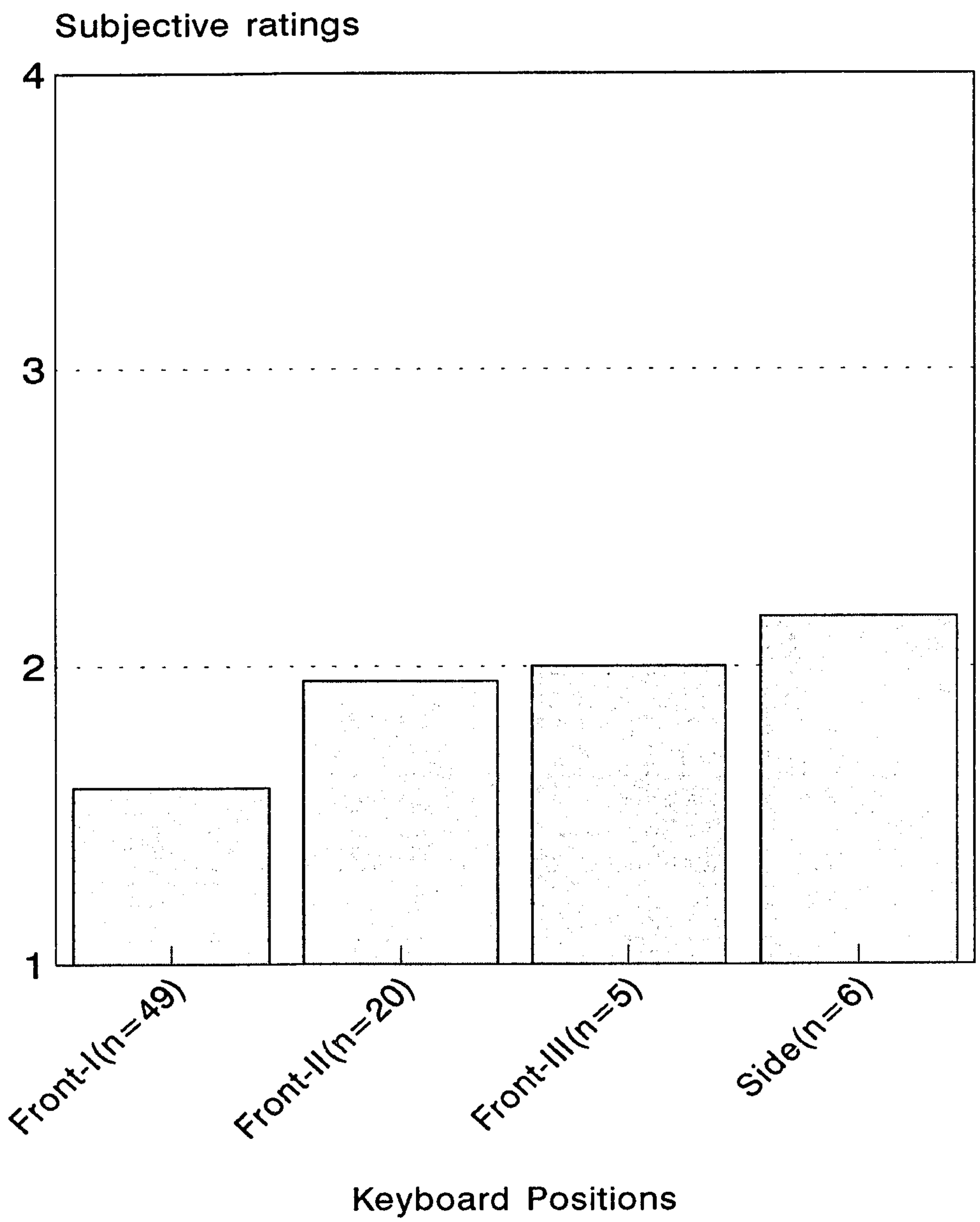


Figure 6.11 Mean ratings for different keyboard positions

The keyboard height was subjectively rated from 1 to 5, representing from 'too high' to 'too low' (KBHS). It is found that 51.2% of operators rated their keyboard either 'too high' or 'too low'. The keyboard height was objectively evaluated with the height of the elbow. The literature recommended that the keyboard should be set at the same height of the elbow when the operator is seated. Large difference (too high or too low) may cause discomfort to the arms and wrists of the operator (Dainoff, 1984). The difference between the keyboard height and elbow height is calculated (DIFF_K_L) for each subject. The correlation between KBHS and DIFF_K_L is -0.52 ($p<0.0001$) which means that the subjective rating and objective measurement are correlated.

Canonical correlation was used to test the relationship between the objective measurement (KBPO and DIFF_K_L) and subjective measurement (KBPS and KBHS) of keyboard position and keyboard height. In order to do the correlation, the absolute value was used for both KBHS and DIFF_K_L variables.

The correlations between the objective and subjective evaluation variables are moderate, the largest being 0.4006 between KBPS and KBPO (Table 6.11). The first canonical correlation is 0.434 ($p<0.001$). So conclusion can be made that the correlation between objective and subjective measurement of keyboard position is significant.

Table 6.11 Correlation of objective and subjective measurement of keyboard position

Objective Measurement	Subjective Measurement	
	KBPS	KBHS
KBPO	0.4006***	0.2382*
DIFF_K_L	0.3562***	0.3443***

Note: * $p<0.05$, ** $p<0.01$, *** $p<0.005$

The canonical redundancy analysis shows that the canonical variables are not a good overall predictor of the opposite set of variables, the proportion of variance explained being 0.1104 and 0.1510. This means if the set of subjective measurements

(KBPS and KBHS) is used to predict the objective evaluation of the keyboard position, the proportion of variance explained by this prediction is only 11%. On the other hand, if the objective evaluation of keyboard position (KBPO and DIFF_K_L) is used to predict the subjective measurement, the proportion of the variance explained by this prediction is only 15%.

The subjective ratings for the comfort of the keyboard position is related to the height of the keyboard (Table 6.11). This might be because several operators rated the keyboard position uncomfortable not only for the inappropriate position but also for the height.

6.4.1.4 CHAIR COMFORT

Chairs used by operators in the survey were all height adjustable with fixed back. The angles between the seat back and seat pan fell into the range of 90 to 105 degree which is specified in ANSI/HFS 100-1988 (ANSI/HFS, 1988).

Two objective measurements were used to evaluate the chair: (1) the difference between the chair height and popliteal height (DIFF_S_P), and (2) presence/absence of arm rests. Three subjective measurements are used: (1) perceived chair height (CHTS), (2) perceived comfort with the back rest (CBR), and (3) perceived comfort with the seat pan (CSP).

According to ANSI/HFS 100-1988, seat height is a function of popliteal heights of the 5th percentile female to the 95th percentile male, shoe heel height, angle of the lower leg as supported by the seating system, and the height and type of foot support provided by the workstation system. In this survey, no foot rest was used by the subjects. The popliteal height of subjects were measured with shoes on. It was assumed that the difference of shoe heel heights due to changing shoes were negligible. The difference between seat height and popliteal height was calculated (DIFF_S_P). The hypothesis was that a large difference between the seat height and popliteal height could affect the subjectively rated seat height.

Arm rests are recommended by the literature to provide stability for the seated posture (Chaffin, 1991). The presence/ absence of arm rests is used to evaluate the chair. The hypothesis was that operators feel more comfortable with chairs that have arm rests.

Figure 6.12 shows the relationship between DIFF_S_P and subjectively rated seat height. It was expected that when DIFF_S_P is within a certain range around zero, the perceived chair height should be 3 (just right); when beyond the range (greater or less), the perceived chair height should be correspondingly rated greater than 3 ("a little too high" to "too high"), or less than 3 ("a little too low" to " too low'). However, Figure 6.11 shows that when DIFF_S_P is less than zero (seat height is less than popliteal height), the subjective rating is from 3 to 4 (from "just right" to "a little lower"); when DIFF_S_P is greater than zero (seat height is greater that popliteal height), the perceived height is from 3 to 1 (from "just right" to "too high"). There are two outliers at the right side of the figure.

Pearson correlation shows that the correlation between the subjective rating of chair height (CHT) and the difference between the chair height and popliteal height (DIFF_S_P) is significant ($r=0.3659$, $p<0.001$). The relative low correlation indicates that other factors may affect subjective judgment of chair height, for example, personal preference and matching with working surface height, etc..

It is also found that the correlation between ARM and CBR is significant ($r = -0.225$, $p<0.05$). This result may imply that the presence of arm rests influences the perceived comfort of chair back rests, i.e., subjects rated the back rest more comfortable for chairs with arm rests.

Canonical correlation was used to examine the relationship between the objective measurements (DIFF_P_S, and ARM) and subjective measurement (CHTS, CBR, and

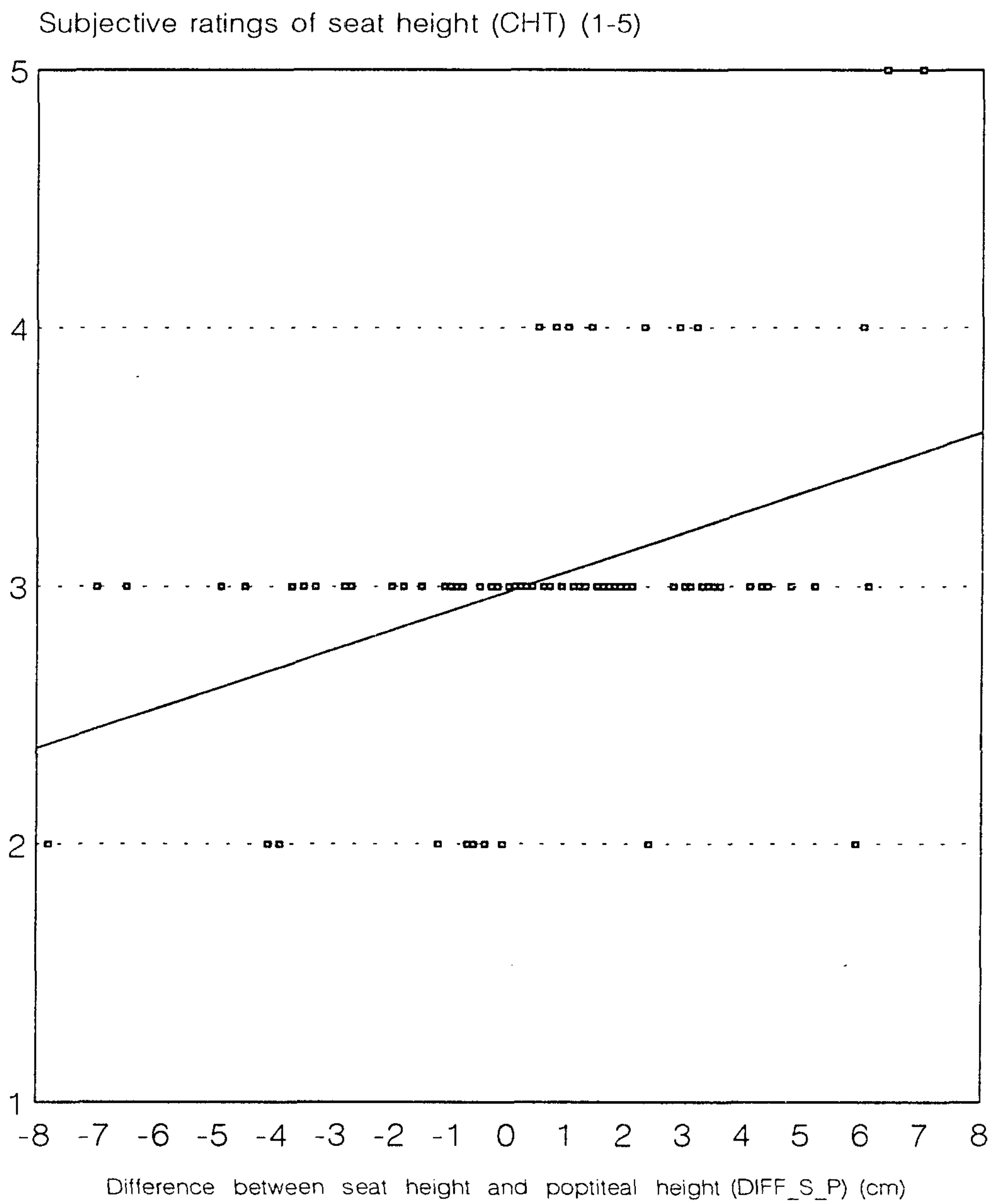


Figure 6.12 The relationship between the perceived seat height and the measurement.

CSP) of chair. The absolute values were used for the variables of DIFF_P_S and CHTS for the correlation analysis with other variables. The canonical correlation is 0.3238 ($p=0.1678$). So no conclusion can be made about the correlation between objective and subjective measurement of chairs for these two sets of variables.

6.5 WORK ENVIRONMENT

6.5.1 LIGHTING CONDITIONS

The following measurements were made at workstations to evaluate lighting conditions (Schleifer et al., 1990): (1) illuminance at the display (DISPLAY_ILLUM), keyboard (KEYBOARD_ILLUM), and document (DOCUMENT_ILLUM) (lx); (2) luminance of display (DISPLAY_LUM), keyboard (KEYBOARD_LUM), and document (DOCUMENT_LUM) (candelas/m^2); and (3) visual foreground luminance: luminance at 30° left of display (LEFT_LUM), 30° right of display (RIGHT_LUM), and directly behind VDT (BACK_LUM) (candelas/m^2).

Two subjective measurement variables were used: (1) perceived illuminance level (ILLUM_LEVEL, from 1 to 5, representing from " too dim" to "too bright"); and (2) perceived comfort with the illumination in work area (ILLUM_COMFORT, from 1 to 4, representing from "comfortable" to "uncomfortable").

6.5.1.1 ILLUMINATION LEVEL AT WORKSTATION

Table 6.12 shows the means of the illuminance measured at display, keyboard, document areas and the overall mean. It shows that the illuminance at screen is lower than that at keyboard and document. This is because screens are nearly vertical to the luminaire while keyboards and most documents are parallel to the luminaire.

ANSI/HFES 100-1988 recommends that "in workplaces with visual display terminals, an illuminance in the range of 200 lux to 500 lux, measured on the work area of the work surface, is normally sufficient". The overall mean of the illuminance at display, keyboard, and document is considered as the average illuminance in work area. Table 6.11 shows that the mean illuminance is a little higher than what is recommended.

Table 6.13 shows the correlations between the measured illumination and subjective rated illumination level. It shows that all measurements have positive correlation with the subjective rating. Canonical correlation shows that the relationship between subjectively rated illuminance and the measurements of illuminance at the display, keyboard, and document is significant ($r=0.362$, $p<0.05$). Further examining the result, it is found that more weight is on the variable of DISPLAY_IllUM in the canonical variable which is the linear combination of the measurement variables (DISPLAY_ILLUM, KEYBOARD_ILLUM, and DOCUMENT_ILLUM). This implies that the relationship is mainly determined by the relationship between the measured display illuminance and subjective rating.

Table 6.12 Illuminance at VDT workstations (lx)

	Mean	Standard Dev.	Range
Display Illuminance	371.09	137.92	129 - 807
Keyboard Illuminance	627.31	225.09	215 - 1184
Document Illuminance	646.41	253.89	161 - 1184
Overall Mean (display, keyboard, and document)	548.27	178.64	233 - 986

Table 6.13 Pearson correlation between objective and subjective measurement of illuminance

	Objective Measurement of Illuminance			
	Display area	Keyboard area	Document area	Avg. at workstation
Subjective Rated Illuminance	.36**	.21*	.12	.24*

Note: *p<.05, **p<.01

In order to examine the relationship between ILLUM_COMFORT and the illuminance at display, keyboard, and document. Each variable of DISPLAY_ILLUM, KEYBOARD_ILLUM, and DOCUMENT_ILLUM was divided into two groups from their median, respectively. The correlation was calculated between each group of the illuminance variable and ILLUM_COMFORT. The result is shown in Table 6.14. It shows that low illuminance at display and high illuminance at document correlate with high level of discomfort.

Table 6.14 Correlation between each group of illuminance measurement separated from its median and subjective rated comfort with illumination level

	ILLUM_COMFORT
DISPLAY_ILLUM	
>= 322.8 (median)	-0.0314
<= 322.8	-0.3169*
KEYBOARD_ILLUM	
>= 538 (median)	0.0313
<= 538	-0.2283
DOCUMENT_ILLUM	
>= 645.6 (median)	0.3125*
<= 645.6	-0.2379

Note: * $p<0.05$

6.5.1.2 LUMINANCE - DISPLAY, KEYBOARD, DOCUMENT, AND BACKGROUND

Since the light meter used for this study starts from 107.6 lux (10 footcandles) for illuminance or 34.3 candelas/m^2 (10 footlamberts) for luminance, background or surfaces with luminance below 34.3 candelas/m^2 can not be measured. The lighting data were divided into several ranges and the results are shown in Table 6.15.

ANSI/HFES 100-1988 recommends that the luminance of visual display shall be able to achieve a luminance of at least 34.3 candelas/m^2 (10 footlamberts) or more. Table 6.15 shows that 23.8% of display has the luminance which is below 34.3

candelas/m^2 (10 footlamberts). The ranges of background luminance (30° left of display, 30° right of display, and directly behind the display) variate greater than that of luminance of display and keyboard by the presence of task lamps or windows.

Table 6.15 Luminance at workstations

	Luminance (candelas/m^2) (footlamberts)		Range (candelas/m^2)(footlamberts)	
	Category	Percent	Minimum	Maximum
Display	< 34.3 (10)	23.8 %	< 34.3	120.05
	< 68.6 (20)	57.5 %	(10)	(35)
	>= 68.6 (20)	18.7 %		
Keyboard	< 34.3 (10)	13.8 %	< 34.3	137.2
	< 68.6 (20)	68.7 %	(10)	(40)
	>= 68.6 (20)	17.5 %		
Document	< 34.3 (10)	0.0 %	34.3	240.1
	< 68.6 (20)	27.5 %	(10)	(70)
	< 102.05(30)	43.8 %		
	>=102.05(30)	18.7 %		
30° left of display	< 34.3 (10)	12.5 %	< 34.3	343
	< 68.6 (20)	45.0 %	(10)	(100)
	< 102.05(30)	16.3 %		
	< 171.5 (40)	12.5 %		
	>=171.5 (40)	13.7 %		
30° right of display	< 34.3 (10)	8.8 %	< 34.3	308.7
	< 68.6 (20)	53.7 %	(10)	(90)
	< 102.05(30)	20.0 %		
	< 171.5 (40)	10.0 %		
	>=171.5 (40)	7.5 %		
Directly back of display	< 34.3 (10)	8.8 %	< 34.3	377.3
	< 68.6 (20)	41.2 %	(10)	(110)
	< 102.05(30)	17.5 %		
	< 171.5 (40)	21.3 %		
	>=171.5 (40)	11.2 %		

Table 6.16 shows the correlation between ILLUM_LEVEL and ILLUM_COMFORT on one hand and the measured luminance on the other hand. It shows that luminance at keyboard, document, and background area have positive correlations with ILLUM_LEVEL. This implies that luminance at work area affect the subjective judgment of the illuminance level. However, no significant correlation has

been found between the perceived comfort with the illuminance and the measured luminance variables.

Table 6.16 Correlation between subjective rating of illuminance and luminance at workstation

	ILLUM_LEVEL	ILLUM_COMFORT
DISPLAY_LUM	.15	.04
KEYBOARD_LUM	.24*	.00
DOCUMENT_LUM	.27*	.01
LEFT_LUM	.29**	-.05
RIGHT_LUM	.07	.00
BACK_LUM	.29**	-.13

In summary, subjective judgment of illumination level in work area is mainly associated with the illuminance at display. It is also affected by the luminance of the keyboard, document, and visual foreground. The perceived comfort with illuminance in work area correlates with the illuminance at display and document. Low illuminance at display and high illuminance at document correlate with high level of discomfort with the illuminance. Luminance of the work area does not affect the perceived comfort with the illuminance.

6.5.1.3 LIGHTING CONDITION AND VISION COMPLAINTS

Correlations between lighting conditions (illumination, luminance, and luminance ratio) and vision complaints are shown in Table 6.17. The luminance ratios of display, keyboard, and document are calculated by dividing their luminance by the luminance of the area behind of (BACK), 30° left (LEFT) and 30° right (RIGHT) of VDT.

It shows that the illumination level at workstation area generally is not correlated with visual complaints. The negative correlation between the illumination at display and the complaint of tired eyes might be suggested that dim illumination is associated with a high level of visual complaint.

Luminance behind VDT has a significant negative correlation with visual complaints of tearing/itching eyes, tired eyes, and burning eyes. Luminance ratios of keyboard and document to the visual foreground (back and 30° right of VDT) also have significant positive correlation with the above visual complaints. The results might be interpreted that dark background is associated with visual complaints.

It is noticed that all visual complaints which are associated with the lighting condition are the symptoms which can be classified as "ocular discomfort" (Schleifer et al. 1990). The visual complaint of blurred vision which is classified as "perceptual discomfort", i.e., blurred/double vision, (Schleifer et al., 1990) is not associated with the lighting conditions.

Table 6.17 Pearson correlations between visual complaints and lighting conditions (n=80)

	Tearing eyes	Tired eyes	Burning eyes	Dry eyes	Blurred vision
Illuminance					
DISPLAY		-.26*			
KEYBOARD					
DOCUMENT					
Luminance					
DISPLAY	-.21*				
KEYBOARD					
DOCUMENT					
BACK	-.23*	-.30**	-.30**		
LEFT					
RIGHT		-.26*			
Luminance ratio DISPLAY/BACK					
DISPLAY/LEFT					
DISPLAY/RIGHT					
KEYBOARD/BACK	.31**	.27*	.35**	.23*	
KEYBOARD/LEFT					
KEYBOARD/RIGHT		.28*	.24*		
DOCUMENT/BACK	.23*	.23*	.28*		
DOCUMENT/LEFT					
DOCUMENT/RIGHT		.24*			

* p<.05
** p<.01

6.5.2 OTHER WORK ENVIRONMENT VARIABLES

Other work environment variables include: perceived noise level, comfort with temperature, humidity, ventilation conditions, working space, and work area privacy. Table 6.18 lists these descriptive data.

Table 6.18 Other environmental variables

Environment variables	Category	Percent
Noise level	No noise at all	15.9%
	Slightly noisy	51.1%
	Moderately noisy	25.0%
	Too noisy	8.0%
Comfort with temperature, humidity, and ventilation conditions	Comfortable	34.1%
	Slightly uncomfortable	33.0%
	Moderately uncomfortable	22.7%
	Uncomfortable	10.2%
Work space	Too cramped	15.9%
	A little too cramped	37.5%
	Just right	46.6%
Work area privacy	Too open	27.3%
	A little too open	31.8%
	Just right	36.4%
	A little too closed	3.4%
	Too closed	1.1%

The results of correlation analysis the environmental variables and other variables show that cramped work space is associated with vision complaints, headache, and psychological stress; privacy of work area is associated with depression; and comfort with temperature is associated with fatigue. However, no significant correlations were found among environmental variables and musculoskeletal complaints (Table 6.19).

6.6 PSYCHOSOCIAL FACTORS

The following variables adapted from past studies (Carey, 1992; Carayon et al., 1992) were used for the investigation of psychosocial factors: time pressure (TMP),

Table 6.19 Correlations between environmental variables and health complaints

	Noise level	Comfort with temperature	Work space	Work area privacy
Vision				
Tearing eyes			-.33**	
Tired eyes			-.21*	
Burning eyes			-.27*	
Dry eyes				
Blurred vision			-.24*	
Musculoskeletal complaints				
Neck				
Shoulders				
Upper back				
Lower back				
Wrists				
General physical complaints				
Headache				
Stomach ache		.21*	-.22*	
Ringing ears				
Psychological stress				
Fatigue		.23*		
Anxiety			-.27*	
Depression			-.32**	-.23*

Note: * $p<0.05$ ** $p<0.01$

surges of work load (SWL), satisfactory with job challenge (JCS), job responsibility (JRS), sense of accomplishment (JSA), supervisor support (SSP), supervisor feedback (SFB), interaction with other people (WIT).

Factor analysis was used to find the common factors for the psychosocial variables. Principle component analysis with Varimax rotation was used. The result is shown in Table 6.19. The factor loadings which are below 0.4 are not shown.

There are two factors: one might be called "job satisfaction" factor and the other "work pressure" factor. "Job satisfaction" factor is related to operators' satisfaction with various aspects of job, such as job challenge, job responsibility, supervisor support and feedback, while "work pressure" factor relates to the operator's feelings of work load. The total variance which can be explained by the two factors is 52.3%. By using these

Table 6.20 Rotated factor pattern for psychosocial factors
(principal component factor analysis + varimax factor rotation)

	Estimated factor loadings		
	F1	F2	Communalities
TMP		.815	.684
SWL		.783	.662
JCS	.708		.521
JRS	.730		.584
JSA	.584		.341
SSP	.745		.589
SFB	.678		.518
WIT	.492		.286

two factors instead of eight variables, further analysis (correlation and regression) with the variables in other categories can be simplified.

6.7 TEST OF RESEARCH MODEL

There are totally 10 categories of variables in the research model (Figure 5.3) with 160 variables from questionnaire, objective measurements, and posture analysis. For testing the hypothesized relationships, data were first simplified by eliminating some variables, then canonical correlation analysis, factor analysis and regression analysis were used.

6.7.1 VARIABLE REDUCTION

Preliminary data analysis was conducted which included frequency analysis, contingency table analysis, and plots. Some variables were eliminated based on the following criteria: (1) skewed data, (2) variables which had no or weak relationship with another category of variables, (3) variables with low factor loadings and where less variance could be explained by the common factors if the factor analysis was applied for this category of data.

Table 6.21 shows the reduced variables that were used to test the research model. The total variables here are 46.

6.7.2 CORRELATIONS AMONG VARIABLES IN THE RESEARCH MODEL

Canonical correlation analysis was applied to each category of variables. The results are shown in Table 6.22 and Figure 6.13. The following observation can be made from the above results.

6.7.2.1 PHYSICAL SYMPTOMS

Musculoskeletal symptoms. This category of variables is significantly associated with 'awkward work posture' and 'psychological stress'. It shows that the third level variables in the research model (i.e., demographics, task, workstation design, work environment and psychosocial factors) have no direct relationship with musculoskeletal symptoms.

Visual symptoms. Many categories of variables have significant relationship with visual symptoms: awkward work posture, psychological stress, task, workstation design, work environment, and psychosocial factors. It is noticed that most third level variables except "Demographics" have direct relationship with "Visual symptoms."

General physical symptoms. The variables that are significantly correlated with general physical symptoms are psychological stress and psychosocial factors. The third level variables have no direct relationship with this category of variables.

6.7.2.2 AWKWARD POSTURE

The factors directly associated with this category of variables are demographics, workstation design, psychosocial factors, and psychological stress.

6.7.2.3 PSYCHOLOGICAL STRESS

Workstation design, work environment, psychosocial factors, and awkward work posture are significantly correlated with this category of variables.

6.7.3 REGRESSION MODELS

In order to reduce the variables for further analysis of risk factors related to physical symptoms by using regression analysis, factor analysis was applied to the

Table 6.21 Reduced variables for testing the research model

Category	Variable name	Explanation
1. Demographics	SEX	Sex
	AGE	Age
	LPJ	Length of time at present job
	EWT	Eye wear type
2. Tasks	TASK	Major task
	WHD	Working hours/day
	TOC	Time of using computer continuously
	TOU	Total time of using computer/day
3. Workstation design	SCG	Subjective rated screen glare
	SGI	Image loss due to screen glare
	LAY	Layout of screen and keyboard
	SCP	Comfort with screen position
	KBP	Comfort with keyboard position
4. Work environment	IUM	Avg. illumination level at workstation
	LUM	Avg. luminance in the visual foreground
		Comfort with illuminance level
	ICR	Comfort with work space
	WSR	
5. Psychosocial factors	TMP	Time pressure
	SWL	Surges of workload
	JCS	Satisfaction with job challenge
	JRS	Job responsibility
	SSP	Supervisor support
	SFB	Supervisor feedback
	WIT	Interaction with other people
6. Work posture	PHN	Head posture
	PTK	Trunk/torso posture
	PUA	Upper arm deviation
	PLA	Lower arm posture
	PWT	Wrist posture
	PFT	Foot posture
7. Psychological factors	UFE	Extreme fatigue
	ANX	Anxiety
	DEP	Depression
8. Musculoskeletal symptoms	NCE	Neck pain
	SHE	Shoulder pain
	UBE	Upper back pain
	LBE	Lower back pain
	WHE	Wrist pain
9. Visual symptoms	TIE	Tearing eyes
	BEE	Burning eyes
	TRE	Tired eye
	DRE	Dried eyes
	BVE	Blurred vision
10.General physical symptoms	HDE	Headaches
	SDE	Stomach ache
	ERE	Ringing ears

Table 6.22 Canonical correlations among 10 categories of variables in the research model

	1	2	3	4	5	6	7	8	9
1. Demographics									
2. Tasks	.49								
3. Workstation	.38	.31							
4. Work environment	.51	.47*	.63**						
5. Psychosocial factors	.59**	.39	.58	.54*					
6. Work posture	.56**	.45	.57**	.44	.59*				
7. Psychological factors	.38	.33	.53**	.46*	.62**	.54*			
8. Musculoskeletal symptoms	.38	.39	.49	.26	.51	.80**	.71**		
9. Visual symptoms	.37	.53*	.55*	.53**	.64*	.71*	.57*	.59**	
10. General physical symptoms	.42	.51	.38	.35	.52*	.57	.64**	.69**	.53**

following categories to identify common factors: psychosocial variables, awkward work posture, musculoskeletal symptoms and workstation design variables.

Physical symptoms. Four factors have been identified: (1) ocular symptom factor (M1), which included the symptoms of burning eyes, tired eyes, tearing/itching eyes, and dry eyes; (2) general musculoskeletal stress factor (M2), which included the symptoms of lower back, neck, shoulders, and headache, (3) upper extremity factor (M3), which included the symptoms of wrists, upper back, shoulders, and neck, (4) other symptom factor (M4), which included blurred vision, ringing ears and stomach ache. The four-factor pattern explained 62% variances of physical symptom variables.

Psychosocial factors. Two factors were identified among psychosocial variables: (1) job satisfaction (S1), which reflected various aspects of satisfaction with the job including satisfaction with job challenge, job responsibility, supervisor support, supervisor feedback, and interaction with other people, and (2) workload pressure (S2), which reflected the subjective feeling of work load including the variables of time pressure and surges of work load. The two-factor pattern explains 51% of the variances of psychosocial variables.

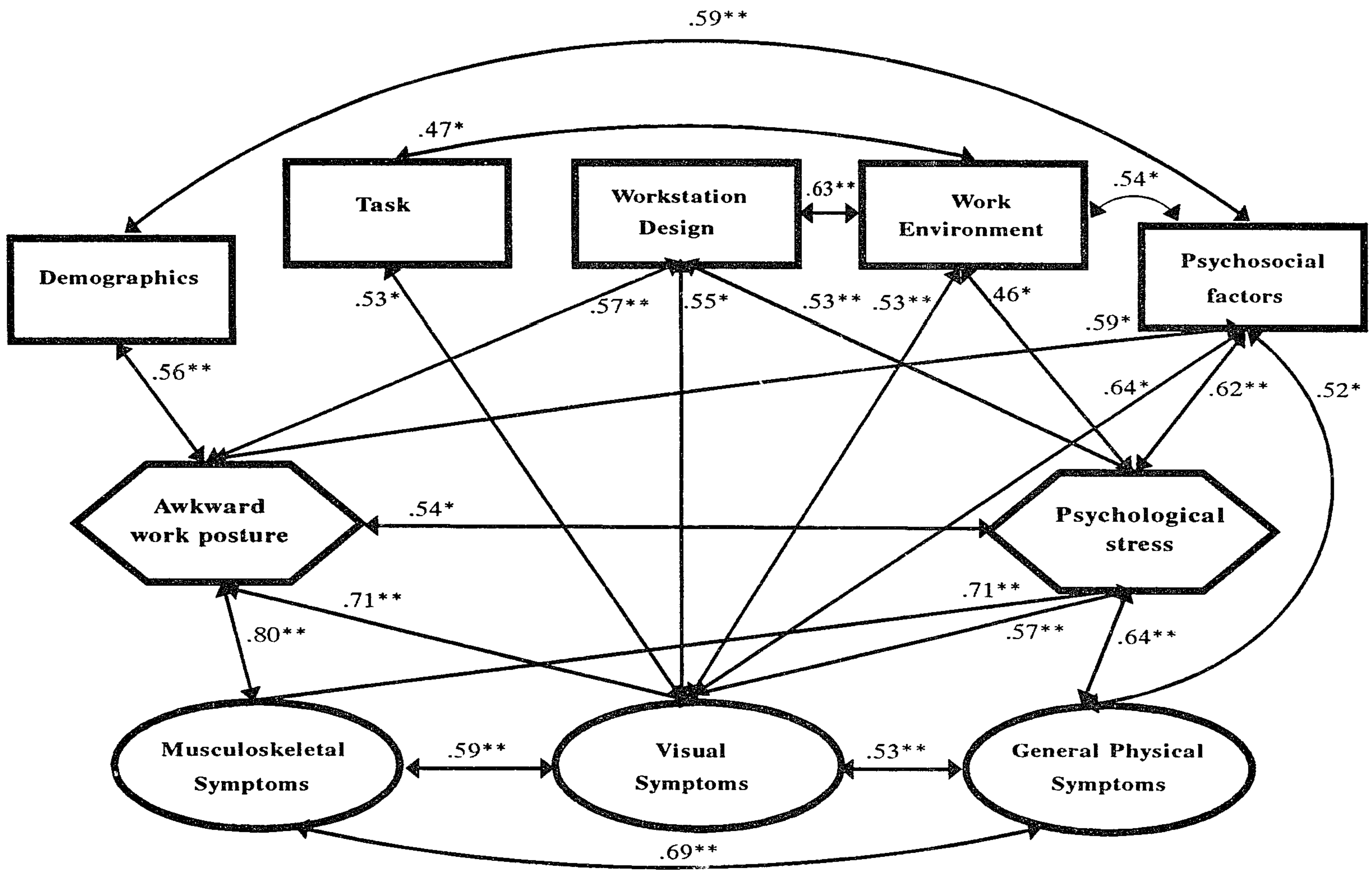


Figure 6.13 Canonical correlations of the research model

Awkward work posture. Two factors were identified: (1) upper body posture (P1), which included the postures of head/neck, trunk, and upper arm, and (2) extremity posture (P2), which included the variables of lower arm, wrist and foot posture. The two-factor pattern explained 61% of the variance of the posture variables.

Workstation design variables. Two factors were identified: (1) screen glare factor (GLARE), which included subjective and objective measurement of screen glare, and (2) layout factor (LAYOUT), which included the layout of keyboard and screen, subjective rating of comfort with screen position, and subjective rating of comfort with keyboard position. The two-factor pattern explains 68% of the variances among workstation design variables.

Table 6.23 lists the reduced variables used as independent variables in the regression models for physical symptoms. It is noticed that posture variables (P1 and P2) and psychological stress variables (DEP, ANX and UFE) are related to both physical symptom variables and environmental variables (i.e. demographics, workstation design, work environment and psychosocial factors) (Figure 6.12). These variables may depend on the environmental variables and they may influence physical symptom variables.

Table 6.23 Independent variables in regression models of physical symptoms

No.	Variables	Categories
1 - 4	SEX, AGE, LPJ, EWT	Demographics
5 - 8	TASK, WHD, TOC TOU	Task
9 - 10	GLARE, LAYOUT	Workstation design
11 - 14	IUM, LUM, ICR, WSR	Work environment
15 - 16	S1, S2	Psychosocial factors S1: job satisfaction S2: work pressure
17 - 18	P1, P2	Awkward work posture P1: upper body posture P2: extremity posture
19 - 21	DEP, ANX, UFE	Psychological stress

Note: see Table 6.21 for variable names.

The following relationships were tested using the multiple regression method. The interactions and their possible effects are listed in Table 6.24.

Regression model 1-2:

Awkward work posture (P1 P2)
$= f$ (demographics, task, workstation design, work environment, psychosocial factors, psychological stress)

Regression model 3-5:

Psychological stress (DEP ANX UFE)
$= f$ (demographics, task, workstation design, work environment, psychosocial factors, awkward work posture)

Regression model 6-9:

Physical symptoms (M1 M2 M3 M4)
$= f$ (demographics, task, workstation design, work environment, psychosocial factors, work posture, psychological stress)

The following regression methods were used to determine the predictors for each regression model: forward, backward, stepwise, and adjusted-R^2. In order to choose the model that provides the best prediction using the sample estimates, several significance levels were tested. The significance level for entering the model by forward selection method was tested at 50 percent (default), 10 percent and five percent. The significance level for leaving model by backward method was tested at 15 percent, 10 percent (default) and five percent. The significant level for entering model in stepwise selection method was tested at 15 percent (default), 10 percent and five percent; for leaving model, 15 percent (default), 10 percent and five percent.

The results from the different methods were compared and the final regression model was determined based on the following criteria: (1) high adjusted R^2, which is an alternative to R^2, which represents the proportion of variiance that can be explained by the model that has been adjusted for the model degrees of freedom; (2) reasonable

Table 6.24 Interaction variables and their possible effects

No.	Interaction Variables	Possible Effect	Justifications
1	AGE x EWT	Visual symptoms	Eye quality may have different effect on visual symptoms for VDT operators at different age. Sjögren and Elfström (1990)
2	TOC x S2	Physical symptoms and psychological stress	The effect of time of using computer may be different when the work pressure is different. Pot et al. (1987) Sauter (1984)
3	TOC x S1	Physical symptoms and psychological stress	The effect of time of using computer may be different when the work atmosphere is different. Pot et al. (1987)
4	EWT x GLARE	Visual symptoms	The effect of screen glare may be different with different eye wear type.
5	EWT x LUM	Visual symptoms	The effect of luminance on visual symptoms may be different for the operators with different eye wear.
6	SEX x S1	Psychological stress	The effect of work pressure may be different for different gender.
7	AGE x S1	Psychological stress	The effect of job satisfaction may be different with different age.
8	SEX x S2	Psychological stress	The effect of job satisfaction may differ by gender.

interpretation; (3) partial R^2, which is the portion of variance that can be explained by the selected parameter; and (4) Cp, which is a measure of total squared error. When the right model is chosen, the parameter estimates are unbiased, and this is reflected in Cp near the number of parameters p in the model (SAS/STAT User's Guide, p.1400).

6.7.4 RISK FACTORS FOR AWKWARD POSTURES

Table 6.25 lists the results of stepwise regression analysis for "awkward work posture".

Table 6.25 Regression results for "awkward work posture"

Variables	Parameter Estimate	Partial R^2	Prob> F
Regression model 1 Dependent variable: P1 (Upper body posture)		R^2=.43 Adj.R^2=.41	.0001
Significant independent variables: POSIT x SCREEN (Keyboard and screen position x Screen glare)	.031	.233	.0001
SEX	.934	.076	.0083
IUM (Avg. illumination level at workstation)	.020	.074	.0050
SEX x S2 (Sex x Work pressure)	.115	.043	.0286
Regression model 2 Dependent variable: P2 (Extremity posture)		R^2=.31 Adj.R^2=.29	.0001
Significant independent variables: SEX x S2 (Sex x Work pressure factor)	-.238	.067	.0003
WSR (Work space)	-.473	.054	.0029
WHD (Working hours/day)	.360	.051	.0085
TOC (Time of using computer continuously)	.160	.038	.0009
IUM (Avg. illumination at workstation)	-.016	.025	.0156

The result shows that the variables related to upper body posture (neck, trunk, and upper arm) are: the interaction between screen and keyboard position, gender, average illumination level at VDT workstation, and the interaction between gender and work pressure. The total proportion of the variance of the upper body posture that can be explained by the above variables after adjustment for the degrees of freedom is 41% (adjusted R^2).

It is seen that the interaction between the layout of screen and keyboard (POSIT) and screen glare (SCREEN) are the most important variables associated with upper body posture. The proportion of the variance of upper body posture that can be explained by this variable is 23.3%. The positive regression coefficient can be interpreted that the bad layout of screen and keyboard and more glare is related to poor/awkward work posture. The effect of interaction between POSIT and SCREEN is shown in Figure 6.14. It is seen that when the score of position is low, the effect of screen glare is not very important. As the score of position increases, high score of screen glare is associated with high score of upper body posture (P1). Gender is another factor which is positively related to the upper body posture: females have higher scores on awkward upper body posture (i.e., worse posture) than males. The average illumination level (average of illumination at display, keyboard, and document) is also positively associated with awkward work posture.

After examination of the effect of interactions of gender (SEX) and work pressure factor (S2) on the upper body posture (P1) (Figure 6.14), it was found that the posture score (P1) increased as work pressure (S2) increased among females but not among males. The effect of work pressure (S2) on upper body posture (P1) among both genders.

The following factors are related to the extremity posture (i.e. lower arm, wrist and foot posture): the interaction between gender and work pressure factor (SEX*S2), work space (WSR), working hours/day (WHD), time of using computer continuously (TOC) and illumination level at workstation (IUM). The negative regression coefficient

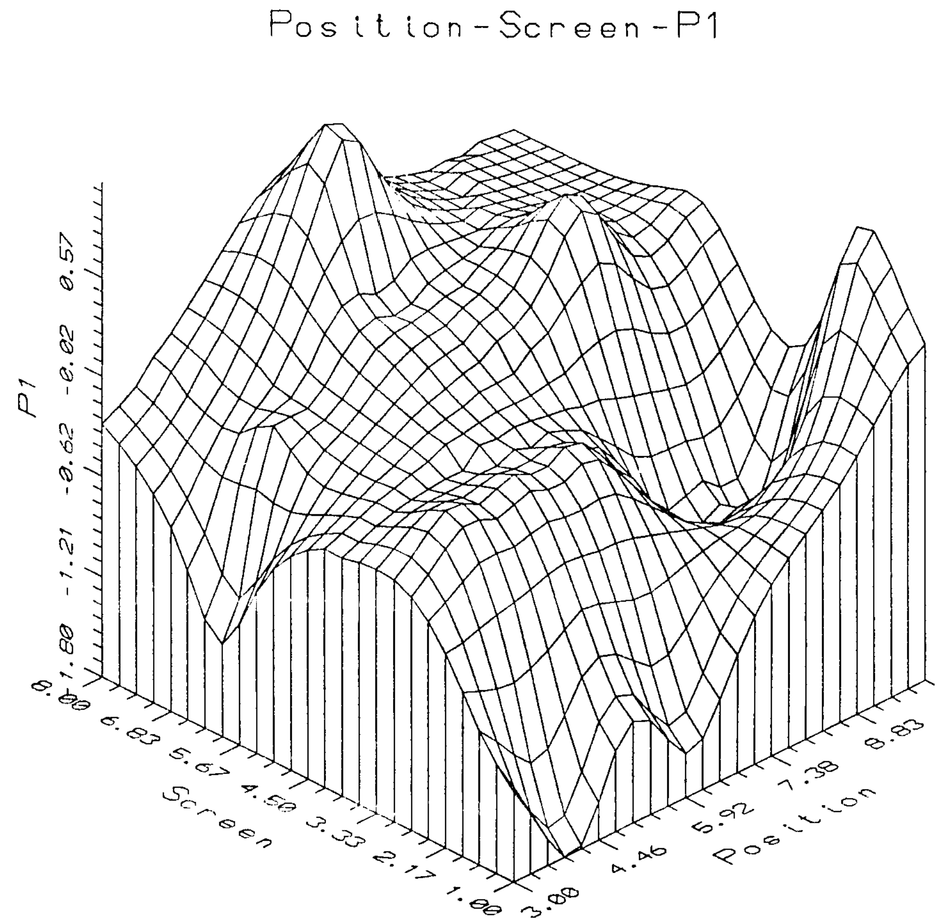


Figure 6.14 Effect of the interaction between the layout of screen and keyboard (POSIT) and screen glare (SCREEN)

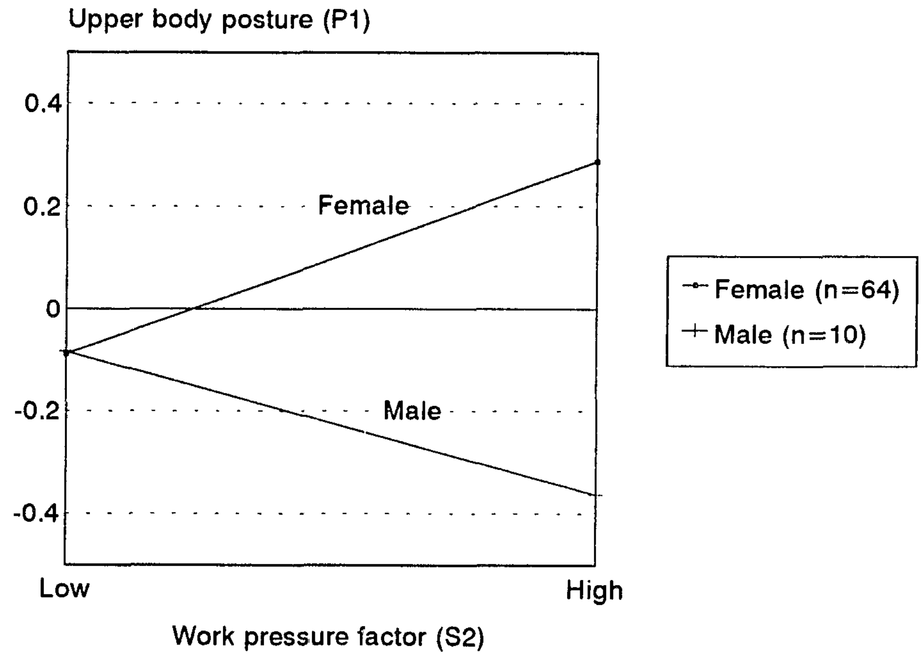


Figure 6.15 Effect of interaction between sex (SEX) and work pressure factor (S2) on upper body posture (P1)

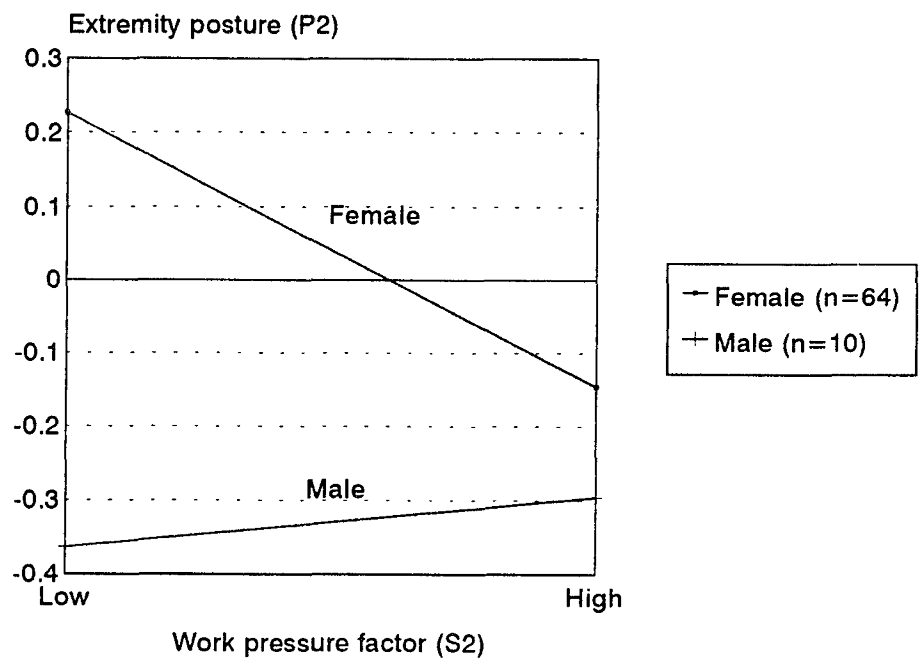


Figure 6.16 Effect of interaction between (SEX) and work pressure factor (S2) on upper body posture (P2)

of work space (WSR) can be interpreted that the more cramped the work space (low rating) the more awkward extremity posture (high score). The positive regression coefficients of WHD and TOC show that working over time and long hours of using computer are associated with more awkward extremity posture. The negative regression coefficient of WHD and TOC shows that the low illumination at workstation is associated with more awkward extremity posture. Following examination of the effect of interaction between gender and work pressure factor (SEX*S2), it is found that the effect of work pressure factor (S2) on extremity posture (P2) is significant among females (F=4.066, df=1, p=0.0482). However, the effect is not significant among males (F=0.389, df=1, p=0.5504).

6.7.5 RISK FACTORS FOR PSYCHOLOGICAL STRESS

Table 6.26 lists the results of stepwise regression analysis for "psychological stress", i.e. depression, anxiety, and extreme fatigue.

The following factors are associated with 'depression': job satisfaction factor, upper body posture factor, average luminance around VDT workstation, work space, the interaction between time of using computer continuously and the layout of screen and keyboard, and the interaction between age and work pressure factor. Job satisfaction factor is the most important factor related to depression which can explain 16.4% of variance of 'depression'. The negative regression coefficient can be interpreted that the more satisfaction with the job, the less depression. Upon examining the interaction between time of using computer continuously and layout of screen and keyboard (TOC*POSIT), it was found that when the time of using computer varied greatly (TOC=0), the effect of layout of screen and keyboard (POSIT) on 'depression' is not significant. As the time of using computer increases, the effect of POSIT on depression becomes more important (Figure 6.17). The interaction of age and work pressure (AGE*S2) shows that the effect of work pressure on depression is significant when the

Table 6.26 Regression results for "psychological stress"

Variables	Parameter Estimated	Partial R^2	Prob> F
Regression model 3 **Dependent variable:** **DEP (Depression)**		R^2=.39 Adj.R^2=.36	.0001
Significant independent variables: S1 (Job satisfaction)	-.491	.164	.0004
P1 (Upper body posture)	.212	.073	.0124
TOC x POSIT (Time of using computer continuously x Position of screen and keyboard)	.013	.045	.0440
LUM (Avg. luminance around VDT)	-.020	.047	.0312
AGE x S2 (Age x Work pressure)	.008	.033	.0788
WSR (Work space rating)	.325	.026	.0991
Regression model 4 **Dependent variable:** **ANX (Anxiety)**		R^2=.31 Adj.R^2=.29	.0008
Significant independent variables: SEX x S2 (Sex x Work pressure factor)	.333	.148	.0003
S1 (Job satisfaction)	-.508	.091	.0029
LUM (Avg. luminance around workstation)	-.023	.040	.0085
TASK (Type of VDT tasks)	.114	.026	.0009
Regression model 5 **Dependent variable:** **UFE (Extremely fatigue)**		R^2=.24 Adj.R^2=.21	.0027
Significant independent variables: SEX x S2 (Sex x Work pressure)	.158	.068	.0274
EWT x LUM (Eye wear type x Avg. luminance around workstation)	-.005	.064	.0280
S1 (Job satisfaction)	-.258	.038	.0818
TASK X LPJ (Type of VDT task x Length of time at present job)	.001	.036	.0869
AGE	-.025	.032	.1016

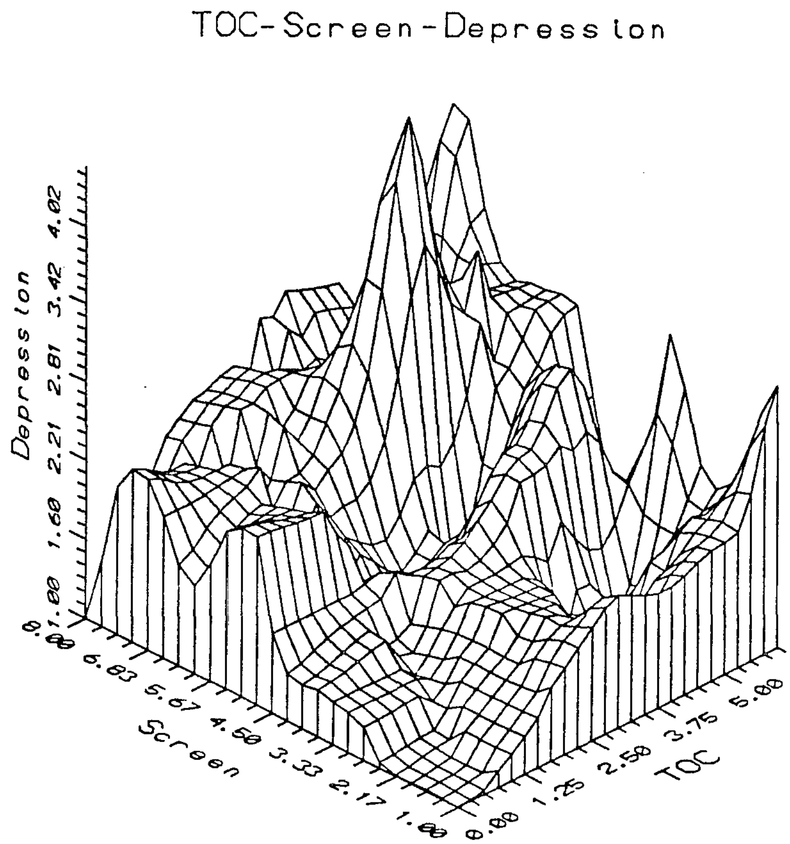


Figure 6.17 The effect of interaction between "time of using continuously" (TOC) and layout of screen and keyboard (POSIT) on depression (DEP)

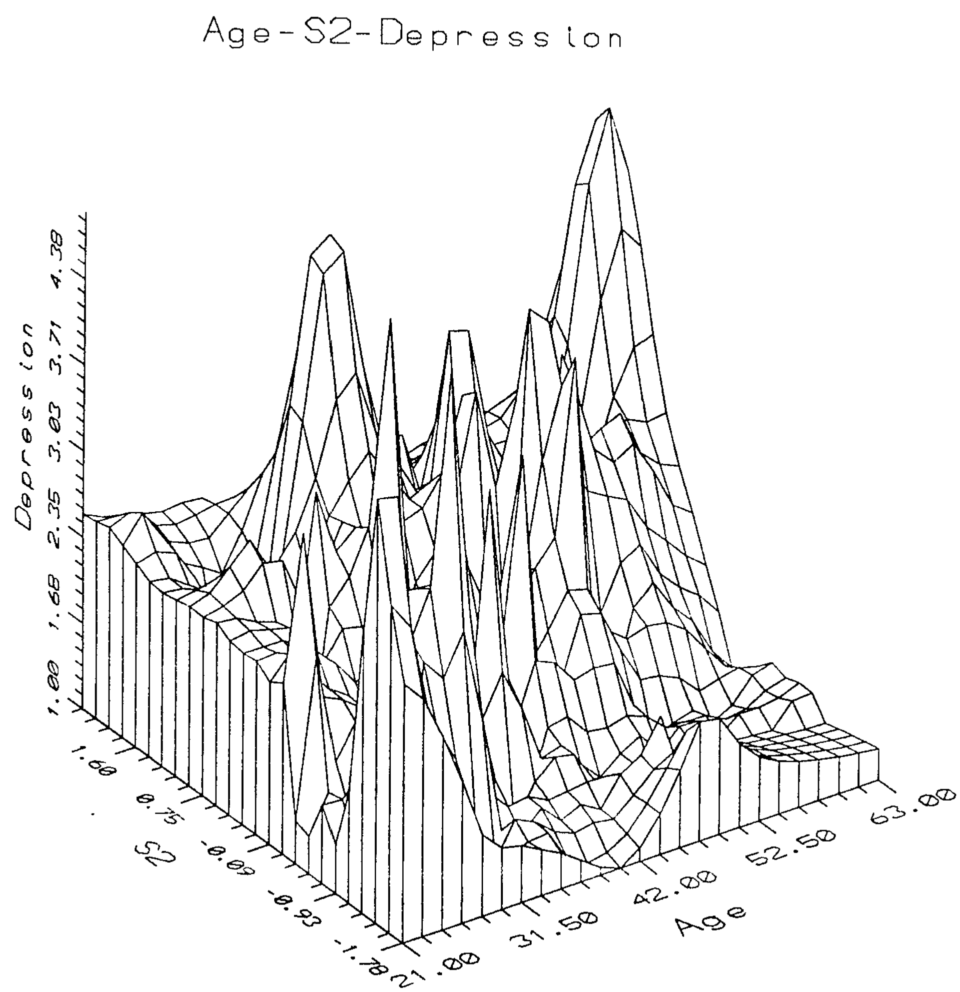


Figure 6.18 The effect of interaction between age (AGE) and work pressure factor (S2) on depression (DEP)

age is over 50, the higher work pressure the operator perceived, the higher depression (Figure 6.18).

The following factors are related to 'anxiety': job satisfaction factor (S1), average luminance around VDT workstation (LUM), the type of VDT tasks (TASK), and the interaction between gender and work pressure (SEX*S2). The interaction between sex and work pressure factor is the most important factor which can explain 15% of the variance in 'anxiety'. The negative regression coefficient of S1 can be interpreted that the more satisfaction with the job, the less anxiety. It is also seen that low luminance is associated with high level of 'anxiety'. The interaction between gender and work pressure (SEX*S2): high work pressure is significantly related to fatigue among females ($F=13.271$, $df=1$, $p=0.0006$) but not among males ($F=0.445$, $df=1$, $p=0.5236$) (Figure 6.19).

The following factors are related to 'extremely fatigue': job satisfaction factor, age, the interaction between sex and work pressure, the interaction between eye wear type and luminance around VDT, and the interaction between type of VDT tasks and length of time at present job. The interaction between gender and work pressure factor (SEX*S2) is the most important factor which can explain 6.8% of variance of 'extreme fatigue'. Examination of above interaction on 'extremely fatigue', it is found that high work pressure is significantly related to high score of fatigue among females ($F=5.058$, $df=1$, $p=0.028$) but not among males (Figure 6.20).

6.7.6 RISK FACTORS FOR PHYSICAL SYMPTOMS

As discussed in section 6.8.3, four factors were identified among physical symptoms, i.e., ocular discomfort (M1), general musculoskeletal stress (M2), upper body symptom (M3), and other physical symptoms (M4). The above four factors are not correlated after the orthogonal transformation (rotation).

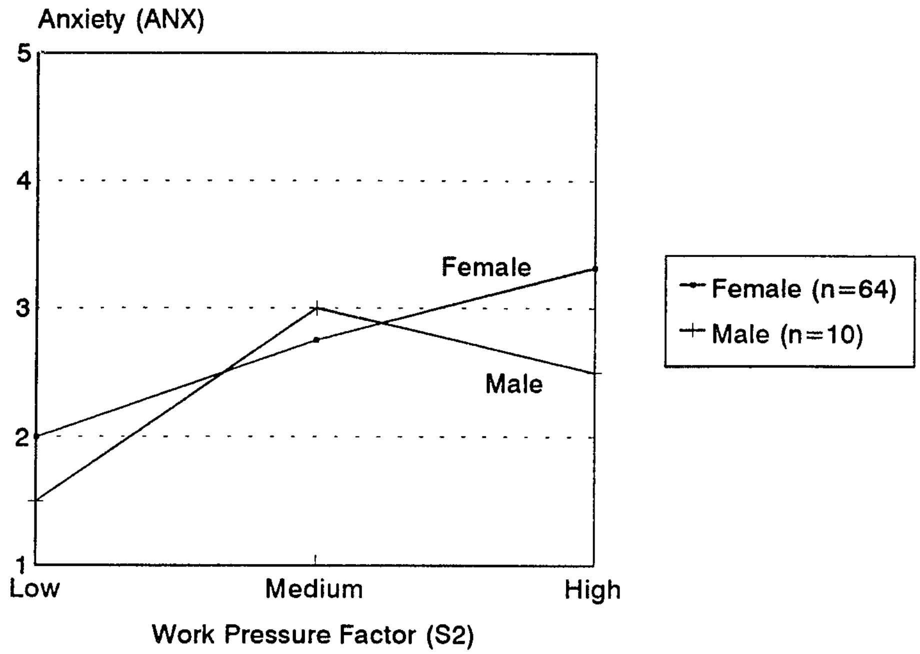


Figure 6.19 The effect of interaction between sex (SEX) and work pressure factor (S2) on "anxiety" (ANX)

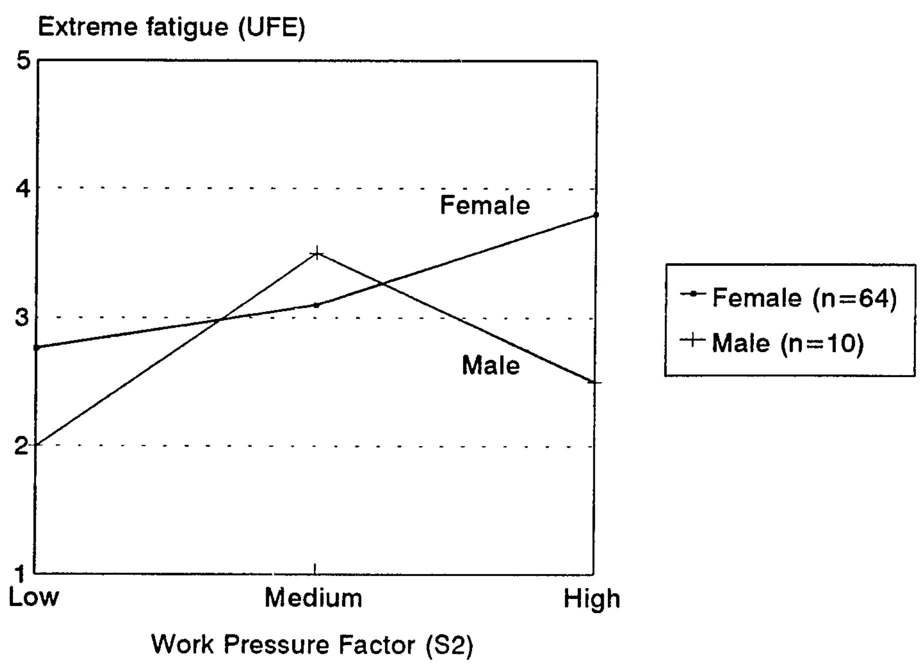


Figure 6.20 The effect of interaction between sex (SEX) and work pressure factor (S2) on "extreme fatigue" (UFE)

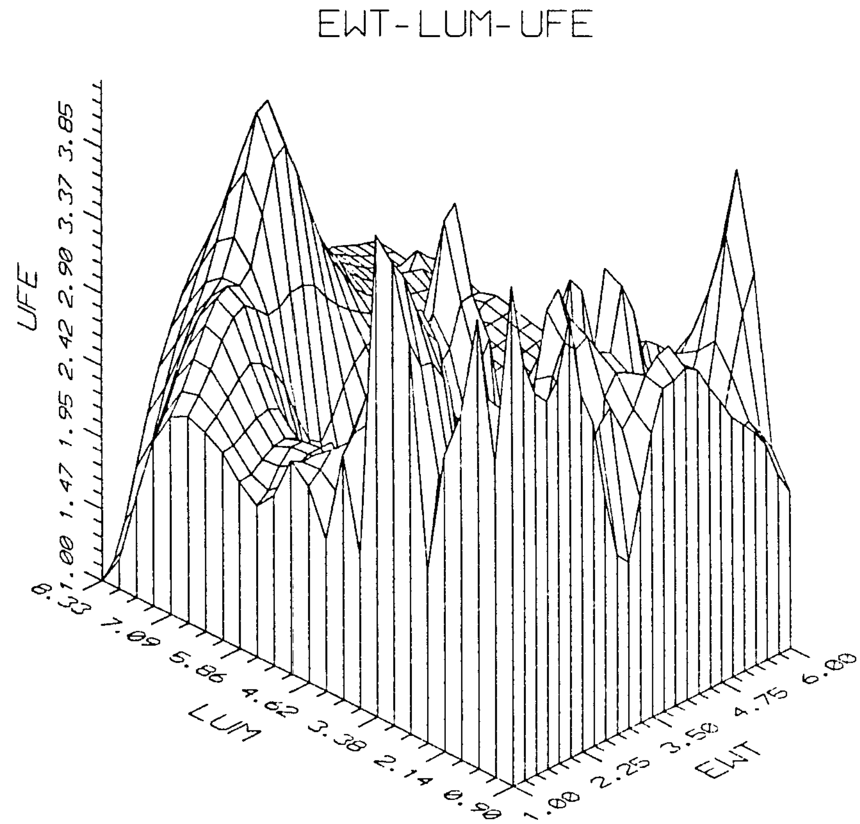


Figure 6.21 The effect of interaction between eye wear type (EWT) and luminance (LUM) on "extreme fatigue" (UFE)

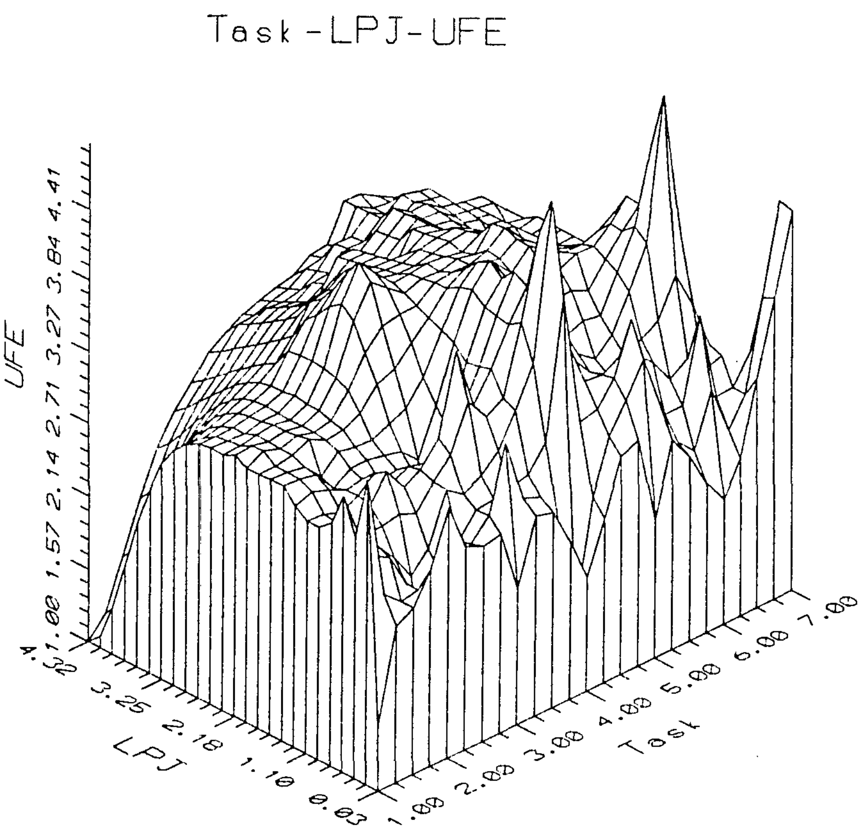


Figure 6.22 The effect of interaction between VDT task (TASK) and length of time at present job (LPJ) on "Extreme fatigue" UFE

M1: Ocular Discomfort

Table 6.27 lists the result of stepwise regression for "ocular discomfort" as a function of demographics, tasks, workstation design, work environment, psychosocial factors, and work posture. It is seen that screen glare is the most important factor related to ocular discomfort. The interaction between TOC (the time of using computer continuously) and POSIT (layout of screen and keyboard) can also explain part of variance of ocular discomfort.

Table 6.27 Regression results for "ocular discomfort" (M1)

Variables	Parameter Estimated	Partial R^2	Prob> F
Regression model 6 **Dependent variable:** **M1** **(Physical symptom 1:** **Ocular discomfort)**		R^2=.39 Adj.R^2=.34	.0001
***Significant independent variables*:** SCREEN (Screen glare)	.149	.101	.0068
TOC x POSIT (Time of computer continuously x Layout of screen and keyboard)	.012	.087	.0080
P2 (Extremity posture)	-.355	.081	.0081
ICR (Discomfort with illumination)	.274	.045	.0394
S1 (Job satisfaction factor)	-.171	.039	.0505
LUM (Avg. luminance around VDT)	-.016	.038	.0610

The effect of interaction between TOC and POSIT is shown in Figure 6.23. It is found that, when TOC=0 (the time of using computer varies greatly), the effect of POSIT on M1 is almost constant. As the TOC increases (the time of continuously using computer increases), both high and low score of POSIT is related with ocular discomfort. Extremity posture (P2) is also associated with ocular discomfort. The negative

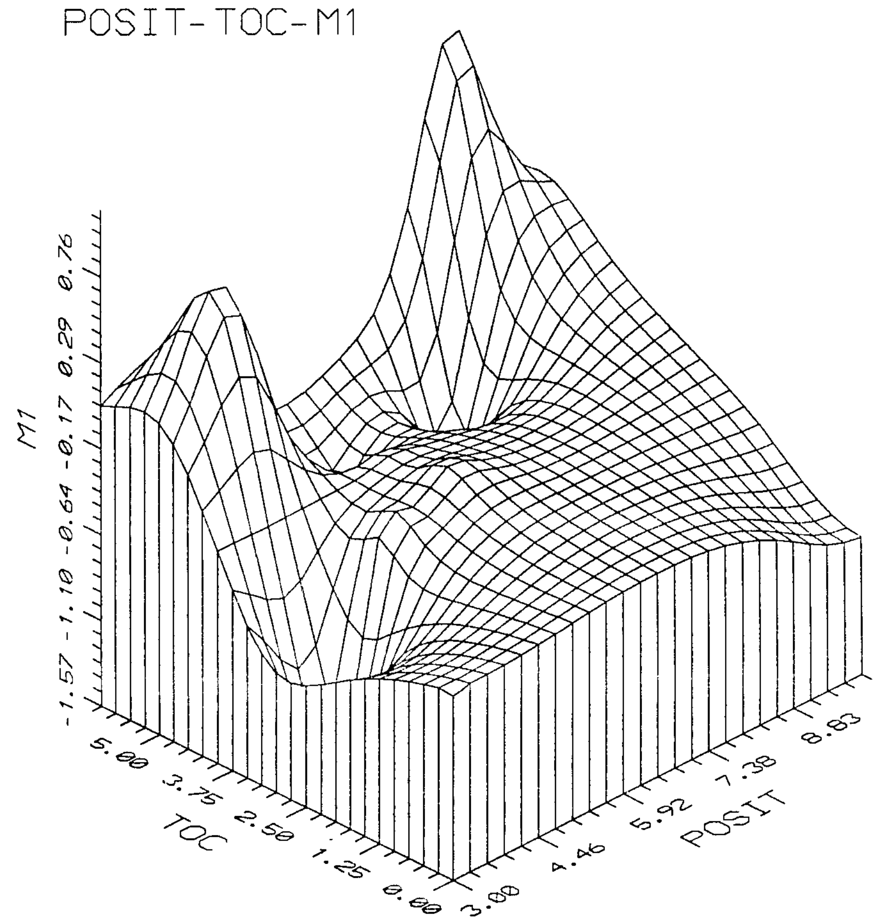


Figure 6.23 The effect of interaction between "time of using computer continuously" (TOC) and "layout of screen and keyboard" (POSIT) on ocular discomfort (M1)

regression coefficient of P2 means that the high score of P2 is related to fewer complaints of ocular discomfort. Further examining the above result, it is found that a high score of P2 is related to a high score of lower arm posture less angle between upper arm and lower arm, see Figure 5.8). This posture might result from a high work surface. The higher the working surface, the closer the document is to the eyes and this may result in fewer ocular complaints.

Table 6.27 also shows that ocular discomfort is associated with discomfort with illumination level at workstation, the more discomfort with illumination, the more ocular discomfort (positive regression coefficient). Job satisfaction factor is another predictor for the ocular discomfort, the negative coefficient reveals that the more satisfied with the job the less complaints. It also shows that low luminance around the workstation is related to more ocular complaints.

M2: General Musculoskeletal Stress

Table 6.28 lists the results of stepwise regression analysis for 'general musculoskeletal stress'. In this factor, lower back pain and headache have high factor loadings (weights). It is seen that 'extreme fatigue' (UFE) is the most important factor contributed to this stress factor. Another factor is P1 (upper body posture). More complaints about general musculoskeletal stress are associated with poor upper body posture. The musculoskeletal complaints are also negatively related to age (AGE) and time of using computer continuously (TOC).

M3: Upper body symptoms

Table 6.29 lists the results of stepwise regression analysis for 'upper body symptoms' (M3). It shows that the following factors are significantly associated with M3: extremity posture (lower arm, wrist, and foot posture), depression, VDT work history, and the interaction between upper body posture (P1) and the layout of screen and keyboard (POSIT). It is found that high scores of extremity posture, depression, and

Table 6.28 Regression results for "general musculoskeletal stress" (M2)

Variables	Parameter Estimated	Partial R^2	Prob> F
Regression model 7 **Dependent variable:** **M2** **(Physical symptom 2: General musculoskeletal stress)**		R^2=.42 Adj.R^2=.38	.0001
Significant independent variables: UFE (Extreme fatigue)	.357	.186	.0002
P1 (Upper body posture)	.203	.125	.0021
AGE (Age)	-.025	.061	.0179
TOC (Time of using computer continuously)	-.244	.043	.0490

Table 6.29 Regression results for "upper body symptoms" (M3)

Variables	Parameter Estimated	Partial R^2	Prob> F
Regression model 8 **Dependent variable:** **M3** **(Physical symptom 3: Upper body symptom)**		R^2=.28 Adj.R^2=.26	.0016
Significant independent variables: P2 (Extremity posture)	.362	.141	.0094
DEP (Depression)	.159	.068	.0242
VDT (VDT work history)	.004	.038	.0816
P1 x POSIT (Upper body posture x Layout of screen and keyboard)	.031	.032	.104

VDT work history are associated with a high score of upper body symptoms (M3). Examination of the interaction between P1 and POSIT, it is found that if the POSIT is high (poor layout of screen and layout), the effect of P1 on M1 is negative.

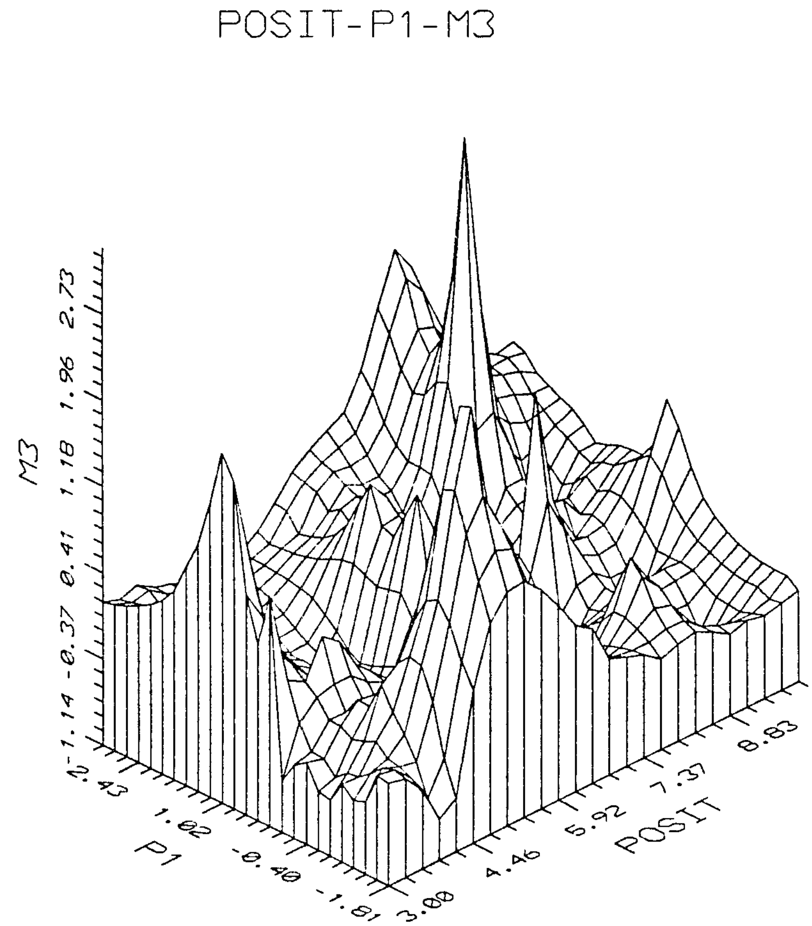


Figure 6.24 The effect of interaction between upper body posture (P1) and the layout of screen and keyboard (POSIT) on "Upper body symptoms" (M3)

M4: Other physical symptoms

Table 6.30 lists the significant variables associated with 'other physical symptoms' (M4) which includes the variables of blurred vision, stomach ache and ringing ears. These variables are extreme fatigue (UFE), total time of using computer per day (TOU), and the interactions between age and eye wear type (AGE x EWT). UFE is the most important factor which can explain 15.6% of variance of M4. The time of using computer per day is also positively related to M4. Examining the effect of interaction of age and eye wear type (Figure 6.25), it is found that as age increases, the factor scores of M4 increases among the operators with 'contact lenses', i.e., more symptoms of blurred vision, stomach ache and ringing ears. Among operators without using any eye wear, M4 declines as the age increases, i.e., more symptoms of blurred vision and ringing ears among younger operators. With other types of eye wear, regular glasses, bifocals, trifocals and others, M4 remains the same as the age increases.

It is noticed that operators who wore 'regular glasses' were between the age of 21 to 49, while the operators who wore 'bifocals, trifocals, and other' were between 40 to 63. The difference of age between the two groups may explain the unchanged scores of M4, i.e. the age range is too narrow to show the difference. When comparing these two groups of operators, it is seen that M4 is slightly higher among the group with 'bifocals and others' than with 'regular glasses', however, the difference is not significant.

Table 6.30 Regression results for "other physical symptoms" (M4)

Variables	Parameter Estimate	Partial R^2	Prob> F
Regression model 9 **Dependent variable: M4** **(Physical symptom 4: Other symptoms)**		R^2=.29 Adj.R^2=.27	.0001
Significant independent variables: UFE (Extreme fatigue)	.243	.156	.0014
TOU (Total time of using computer/day)	.157	.077	.0256
Age x EWT (Age x type of eye wear)	-.003	.059	.0510

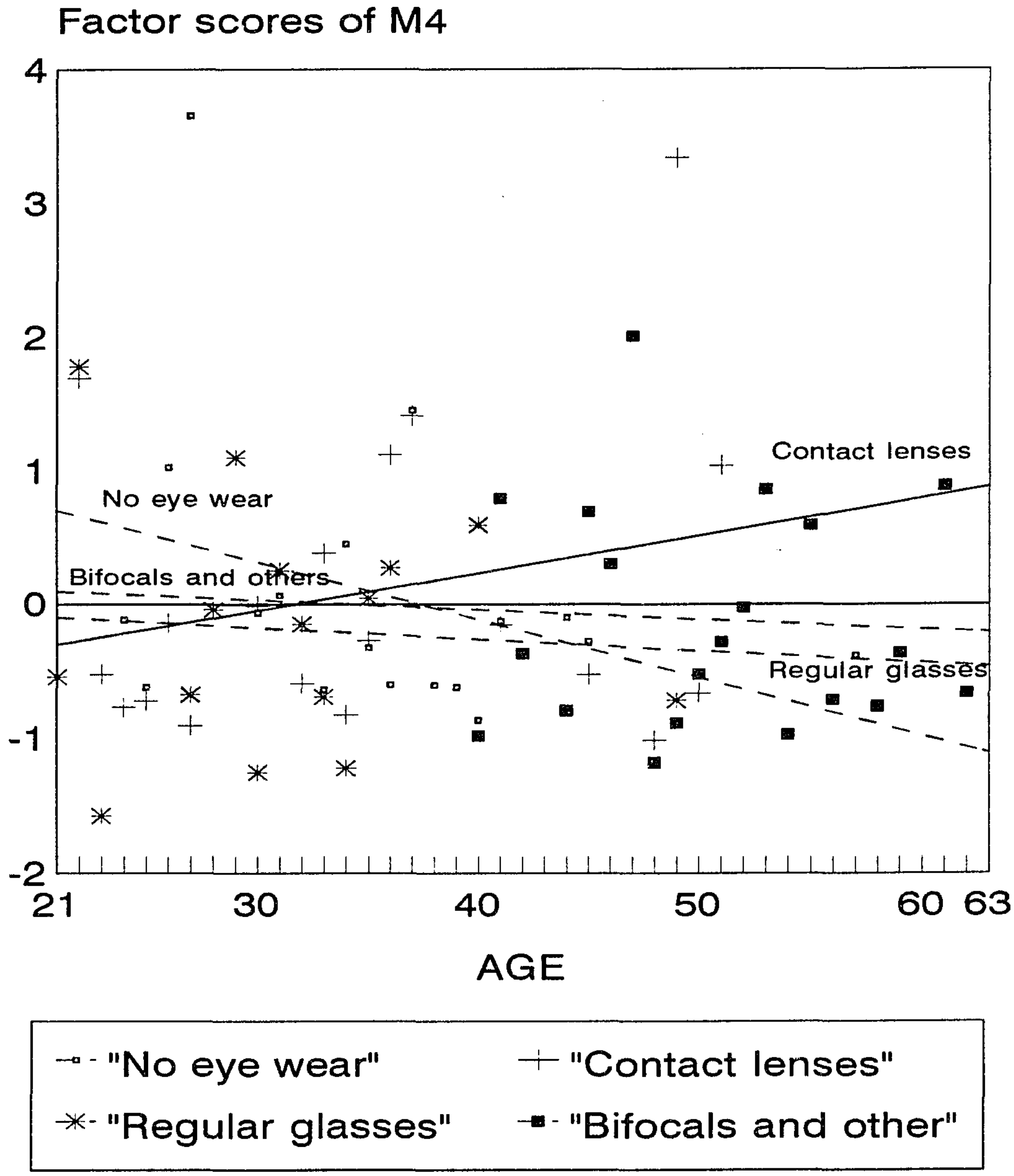


Figure 6.25 The effect of interaction between age (AGE) and type of eye wear (EWT) on "Other physical symptoms" (M4)

CHAPTER 7

DISCUSSION

7.1 RESEARCH MODEL

This study represents an attempt to explain the relationship between the risk factors in a VDT workstation system and their effect on physical symptoms experienced by VDT operators.

It was hypothesized that the interaction of the system components have effects on the physical symptoms via their effect on the awkward work posture and psychological stress. Awkward work posture and psychological stress are directly related to physical symptoms. It was also hypothesized that interactions exist among both the risk factors and physical symptoms.

7.1.1 PHYSICAL SYMPTOMS

As Figure 6.12 shows, the three categories of physical symptom variables are correlated with each other. This confirms the Hypothesis I in Chapter 5. This relationship was also found by other studies among VDT operators (Lu et al. 1993a and 1993b). This relationship may exist because these physical symptoms are pathologically related to each other. For example, visual symptoms and neck pain may cause headache (Zacharkow, 1988). It might also suggest that operators who have one type of physical discomfort are more sensitive to or tend to report on other types of physical symptoms.

Factor analysis shows four (4) factors among the physical symptoms; i.e. ocular discomfort (M1), general musculoskeletal symptoms (M2), upper body discomfort (M3), and other physical symptoms (M4). The variables of the four factors are a little different from the original classifications (Figure 4.1 and Figure 5.3). For visual symptoms defined in the research model, the variable "blurred vision" is separated from M1 (ocular discomfort) in factor analysis. This result is not surprising because all other variables of "visual symptoms" can be classified as "ocular" symptoms and the "blurred vision" is usually considered as "perceptual" or "visual" symptom which is the incident of impaired vision (Bruno, 1993; Collins, et al., 1990; Howarth and Istance, 1986; Laubli, 1981; Schleifer, et al., 1990). For musculoskeletal symptoms in the research model, the variables are divided into two groups, general musculoskeletal symptoms (M2) and upper body symptoms (M3). In the factor M2, the variables of "lower back" and "headache" have the highest loadings. The reason may be that they are all stress related and are not related to computer use. The regression analysis result shows that this factor is negatively affected by the duration of using VDTs continuously. Factor M3 contains all musculoskeletal symptoms on upper body, i.e., neck, shoulders, upper arms, and upper back. Among the variables in factor M3, the variable of "upper back" has the highest factor loading. For the "general physical symptoms" defined in the research model, the variable of "headache" belongs to M2, and "ringing ears" and "stomach ache" are grouped to factor M4, other physical symptoms. However, the factor loading of "stomach ache" is low.

In summary, the three categories of physical symptoms are correlated. A four-factor pattern is found among the physical symptoms.

7.1.2 PSYCHOLOGICAL STRESS

The measurements for psychological stress are extreme fatigue, anxiety, and depression. It was hypothesized that psychological stress had a direct effect on physical symptoms (Hypothesis II). Canonical correlation analysis shows that psychological stress is significantly related to all three categories of physical symptoms (Figure 6.5). However, the regression analysis shows that only one of these three variables is selected by the regression models for M2 (general musculoskeletal stress), M3 (upper body symptoms) and M4 (other physical symptoms) (see Table 6.28, 6.29 and 6.30) and none of them is selected for M1 (ocular symptoms). The above results can be explained as follows. It is found that these three variables are highly correlated (Table 6.6). Since the regression model selects the most important predictors, it is reasonable that only one of the three variables which are highly correlated was selected for M2, M3 and M4. For M1, the psychological stress variables are not selected because they may not be as important as other variables (e.g., workstation design and work environment). From the above results, conclusion can still be made that psychological stress is directly related to physical symptoms. This result agrees with past studies which found that stress associated with VDT use contributed to cumulative musculoskeletal disorders (Sauter et al., 1992; Smith et al., 1981; Smith et al., 1992; Lim and Carayon, 1993).

7.1.3 WORKING POSTURE

It was hypothesized that working posture is related to psychological stress and all three categories of physical symptoms.

Canonical correlation analysis shows that working posture is significantly related to psychological stress, musculoskeletal symptoms, and visual symptoms. However, working posture is not found to be significantly related to general physical symptoms. The above results support Hypothesis III by which working posture and psychological stress are assumed to be correlated. The results also partly support Hypothesis IV where working posture is assumed to affect physical symptoms directly.

Posture variables are divided into two factors by factor analysis, upper body posture (P1) and extremity posture (P2). In examining the regression analysis result, it is found that P1 is the significant predictor for "General musculoskeletal symptoms" (M2). This result may be interpreted to mean that poor upper body posture (deviation from neutral position at head/neck, trunk and upper arm) contributes to the symptoms at lower back, neck, shoulders, and headache. This result agrees with the findings by other studies (Boussenna et al. 1982; Grandjean et al., 1982; Hunting et al., 1981; Life and Pheasant, 1984; Maeda et al., 1982; Sauter et al., 1983; Zacharkow, 1988).

The interaction of P1 and the layout of screen and keyboard (POSIT) is significant to "Upper body symptoms" (M3) (Table 6.29). When examining Figure 6.24, it shows that when the score of POSIT increases (i.e., the workstation layout is worse), the score for M3 (upper body symptoms) increases as the score of P1 increases. This result shows that the effect of poor working posture on upper body musculoskeletal symptoms (i.e., the symptoms of wrist, upper back, neck and shoulder) is more significant with an improperly designed workstation. In the study by Lim and Carayon (1993), "Ergonomics risk factors" which includes repetition and awkward postures, were found directly associated with upper extremity musculoskeletal symptoms. Other studies show that an increased forward tilt of the head will result in an increased static loading of the posterior neck muscles, as well as an increase in the cervical spine compression forces (Chaffin, 1973; Less and Eickelberg, 1976). However, no previous research is found which examines the interaction of working posture and workstation design.

It is also found that P2 is significant to "Ocular discomfort" (M1) (Table 6.27). The effect of awkward working posture on ocular symptoms may be because of the change of viewing distance to the display, keyboard, and document. It was expected that upper body posture might contribute to the ocular symptoms since poor trunk posture may lead to close viewing distance and cause eye fatigue. However, this relationship is not significant for the present data.

No significant relationship was found between the working posture and the other physical symptoms (i.e., blurred vision, ringing ears, and stomach ache). This result is not surprising because the above physical symptoms may not have a direct relationship with the working posture.

From the above analysis, it is concluded that working posture is directly related to the musculoskeletal and ocular symptoms but not the "other physical symptoms".

7.1.4 DEMOGRAPHICS

The significant relationship between demographics and awkward posture and psychosocial factors found in canonical analysis suggest that interactions might exist between demographics, working posture and psychosocial factors.

Among the variables of demographics, only the variable "Age" and the interaction of "Age" and "Eye wear type (EWT)" were found to be significant to the variables of physical symptoms. It is noticed that age is negatively related to the "general musculoskeletal stress (M2) (i.e. discomfort at lower back, neck, shoulders, and headache)." This finding agrees with that of the study by Sauter (1984) where the increasing age was found to predict reduced strain. The effect is said to attribute to survival, "healthy worker" effect (Sauter, 1984).

The interaction of "Eye wear type" (EWT) and "Age" is found to be related to 'other physical symptoms'. It indicates that with different eye wear type, the effect of age on the physical symptoms is different. It is noticed that the factor score of M4 increases as the age increases among the operators with "contact lenses "(Figure 6.25).

It is found that the variable of "Sex" has significant effect on the "Awkward work posture" (Table 6.25). The interaction of sex and work pressure factor (SEX*S2) on work posture was also found. Other interactions between demographics variables and psychosocial factors on physiological stress were found (i.e., Age*Work pressure and Sex*Work pressure factor).

The above results partially support Hypothesis VI where demographics variables are assumed to interact with task, workstation design, work environment, and psychosocial factors. Hypothesis V is also partially supported by the effect of demographics on work posture and psychological stress.

7.1.5 TASK

The canonical correlation analysis shows that the task variables which include the type of VDT tasks, working hours/day, time of using computer continuously, and total time of using computer per day are significantly correlated with visual symptoms and work environment. This finding is reasonable because the task variables defined here represent the amount and forms of exposure to VDTs which have been found to be related to visual symptoms by past research (Läubli and Grandjean, 1984). The relationship between task variables and work environment variables suggest that interactions might exist between these two sets of variables and have influence on the physical symptoms.

Task variables are also found to be related to all variables of psychological stress, and the interactions exist between task variables, workstation design and demographics variables. It is noticed that the variable WHD (working hours/day) is associated with the posture factor P2 (extremity posture which includes the variables of lower arms, wrists and feet). This may suggest that poor extremity posture may be the result of fatigue caused by longer working hours.

The above findings support the hypothesis VII where task variables are assumed to be associated with awkward posture and psychological stress.

7.1.6 WORKSTATION DESIGN

The variables of workstation design have significant relationship with awkward work posture, psychological stress, and visual symptoms. However, the relationships between workstation design and musculoskeletal symptoms, and workstation design and general physical symptoms are not significant. This might suggest that musculoskeletal symptoms are affected by workstation variables indirectly via their impact on work posture and physiological stress. In examining the canonical variables of workstation design and visual symptoms, it was found that the most important variables related to visual symptoms were screen glare variables. The relationship between workstation design and work environment is also determined by screen glare variables and light conditions.

The above result supports the hypothesis which assumed that the workstation variables are associated with awkward posture and psychological stress.

7.1.7 WORK ENVIRONMENT

Work environment variables are significantly related to task variables, workstation design, psychosocial factors and psychological stress. This result suggests that work environment variables have interactions with many components in the VDT systems to affect physical symptoms. The interaction between the variable of luminance around VDT (LUM) and eye wear type (EWT) is found to be significant to the psychological stress variable and extreme fatigue (UFE). The variable IUM (average illumination level around VDT) is found to be related to both factors of "awkward posture", upper body posture (P1) and extremity posture (P2). The regression analysis (Table 6.25) also indicates that the variable of "comfort with work space" is a predictor for extremity posture. The more cramped the space that an operator has, the poorer the posture. The above results support the Hypothesis IX which assumed that work environment variables be associated with posture and psychological stress.

Work environment variables are also found to directly affect visual symptoms. The variable LUM (average luminance around VDT) is found to be negatively associated with the 'Ocular discomfort'(M1). The result can be interpreted that VDT operators feel more comfort with brighter background.

The variable of "comfort with temperature, humidity and ventilation conditions" was found to be related to the "headache" and "extreme fatigue". This result suggests that the environment is related to the physical and psychological stress.

The variable of "noise level" was not found to be related to any physical symptoms. This may be because that the variations of this variable is not large enough for testing the effect although the noise level was observed higher in the Business Office of OLL than other offices. Another reason may be that the information from the measurement (questionnaire) is not enough for testing the effect. More variables should be used including some objective measurement.

7.1.8 PSYCHOSOCIAL FACTORS

Psychosocial factors are significantly related to many sets of variables which include demographics, work environment, awkward posture, psychological stress, visual symptoms, and general physical symptoms (Table 6.22 and Figure 6.13). This finding suggests that psychosocial factors are important variables that affect operators' health complaints.

Kalimo (1987) states that psychosocial factors are critical in both the causation and the prevention of disease and in the promotion of health. Many past studies conclude that psychosocial aspects of the workplace contributing to both physical symptoms and psychological stress (Bergqvist et al., 1990; NIOSH, 1992; Sauter, et al. 1992; Smith et al. 1992). The above result agrees with the findings of past studies. In addition, it shows that psychosocial factors are not only important risk factors which affect the work postures, psychological stress and physical stress in a VDT workstation system but also important risk factors that interact with other system components. The effect of the interaction of psychosocial factors with other factors is complicated.

7.2 THE MOST IMPORTANT RISK FACTORS AT VDT WORKSTATION

7.2.1 RISK FACTORS TO PHYSICAL SYMPTOMS

As discussed in Chapter 6, the physical symptoms were classified into four different categories after factor analysis, i.e. ocular discomfort (M1), general musculoskeletal symptoms (M2), upper body symptoms (M3), and other physical symptoms (M4). This classification is slightly different from previous classification of the physical symptoms in the research model where the physical symptoms were classified into three groups. The advantage of this classification, as derived from factor analysis, is that the variables within each group are highly correlated and can be explained statistically by a common factor. Another advantage is that the four factors are orthogonal (not correlated), multiple regression analysis can be applied instead of multivariate multiple regression. The analysis and interpretation can therefore be simplified.

The variables associated with the physical symptoms determined by regression analysis can be considered as the most important risk factors among others. These factors are discussed below for the above four categories of physical symptoms.

7.2.1.1 OCULAR DISCOMFORT

Ocular discomfort includes the symptoms of tired eyes, burning eyes, tearing/itching eyes, and dry eyes. Screen glare (SCREEN) is the most important factor related to visual symptoms. The interaction of TOC and POSIT (time using computer continuously and position of screen and keyboard) is another important factor accounting for the variance of ocular discomfort. It suggests that as the time of using computer increases, the ocular discomfort increases. Luminance and illuminance around VDT workstations are also important factors for ocular discomfort. Discomfort with illumination level and low luminance level are associated with ocular discomfort. Job satisfaction and extremity posture also contribute to the symptoms.

Interestingly, the symptom of 'blurred/double vision' which was defined as a visual symptom does not belong to this factor. However, it was not surprising because this symptom was also found to be apart from 'ocular symptom' and was called 'perceptual symptom' by other researchers (Schleifer et al., 1990).

In summary, many factors contribute to ocular discomfort. The important risk factors for ocular discomfort at VDT workstation include factors of workstation design, lighting conditions, psychosocial factors, posture and time of using computer continuously.

7.2.1.2 GENERAL MUSCULOSKELETAL SYMPTOMS

General musculoskeletal symptoms include the symptoms of low back, headache, neck and shoulders. Extreme fatigue is the most important factor in this category of discomfort. Another important risk factor is upper body posture (P1). The poorer the upper body posture (i.e., increased head/neck tilt, increased trunk angle and upper arm angle) the more risk of musculoskeletal complaints at lower back, neck, shoulder areas and headache. Age is also a risk factor to the general musculoskeletal symptoms.

7.2.1.3 UPPER BODY MUSCULOSKELETAL SYMPTOMS

This category of variables includes all the symptoms above the low back, i.e. neck, shoulders, wrists, and upper back. As Tables 6.29 indicates that the extremity posture accounts for a large amount of variance of the upper body musculoskeletal symptoms. This result suggests that deviation from neutral position of low arms affects the upper body musculoskeletal symptoms. Another risk factor is depression, a psychological stress factor. This result supports Hypothesis II that psychological stress may affect musculoskeletal discomfort. This finding agrees with the result of another study by Lim and Carayon (1993). VDT work history is also an important factor to the upper body symptoms. This result suggests that poor upper body posture at VDT workstation may result from long-time computer use. Upper body posture interacting with the layout of screen and keyboard also affects the upper body symptoms.

To summarize, the important risk factors to upper body symptoms (i.e., musculoskeletal complaints at neck, shoulder, upper back and wrist area) are awkward posture, VDT work history, psychological stress and the interaction between upper body posture and the layout of screen and keyboard.

7.2.1.4 OTHER PHYSICAL SYMPTOMS

This category include the symptoms of blurred vision, ringing ears and stomach ache. These results indicate that fatigue is the most important factor for this category of variables. This result suggests that these symptoms are stress related. Another risk factor is the total time spent using the computer per day. The longer time using a computer is associated with higher scores for "other physical symptoms." This result suggests that long time computer use is related to stress. The interaction of age and the type of eye wear also affects the "other physical symptoms." Examination of the interaction found that operators wearing contact lenses have high complaints of these symptoms.

The risk factors to the "other physical symptoms" can be summarized as psychological stress, length of time using computer and demographics.

7.2.2 RISK FACTORS TO AWKWARD WORK POSTURE

The most important risk factors to upper body posture, i.e., head/neck, trunk and upper arm posture, are the interaction of the layout of screen and keyboard and screen glare. For poor workstation design, the screen glare is more significant to affect upper body posture. Other risk factors are sex, average illumination level at workstation and the interaction between sex and work pressure factor (S2). The most important risk factors to extremity posture are the interaction of sex and work pressure factor (S2), comfort with work space, working hours per day, time of using computer continuously and the illumination level at VDT workstation. The above risk factors come from the categories of workstation design, demographics, tasks, work environment and psychosocial factors. The results indicate that working posture is determined by the interaction of many factors in the work place. Among these factors that affect work posture, the features of workstation layout (e.g. the height, orientation, and location of

VDT, keyboard and supporting surface) are most important as these factors determine how a worker must position his/her body when performing a task. Many past studies have found that a poorly designed workstation is associated with increasing musculoskeletal complaints from VDT operators (Hunting et al., 1981; Maeda et al., 1982; Sauter et al., 1983), although the present study did not fully confirm this for the neck, shoulders and lower back.

7.2.3 RISK FACTORS TO PSYCHOLOGICAL STRESS

Many factors affect psychological stress (Table 6.26). These factors include psychosocial factors, work environment, workstation design, tasks and demographics. Among these factors, psychosocial factors, i.e. job satisfaction and work pressure factors, are most important for all the variables used to measure psychological stress, i.e. depression, anxiety and extreme fatigue. This result agrees with past studies in which psychosocial factors are found to be significant predictors of psychological stress (Järvenpää et al., 1993; Miezio, et al., 1987; Rogers et al., 1990).

7.3 INTERACTIONS AMONG RISK FACTORS

As discussed above, there are many factors that may create harmful loads on an individual in a VDT workstation system. These factors interact when work is being done. However, very few studies have examined the interactions of these risk factors. This study examined the interactions of the factors within and between the system components in the VDT workstation system. Among these interactions, the layout of screen and keyboard is found to interact with other factors, screen glare, time of using computer continuously and extremity posture, and to affect upper body posture, general musculoskeletal symptoms, ocular discomfort and psychological stress. Psychosocial factors are important factors interacting with other factors and affecting the psychological stress and awkward working posture. Among the variables of demographics, sex and age are the factors that interact with other variables affecting the

Table 7.1 Summary of interactions of risk factors

Interaction Variables	Explanation	Affected Variables
POSIT*SCREEN	Layout of screen and keyboard and screen glare	Upper body posture (P1)
SEX*S2	Sex and work pressure factor	Upper body posture (P1)
SEX*S2	Sex and work pressure factor	Extremity posture (P2)
TOC*POSIT	Time of using computer continuously and the layout of screen and keyboard	Depression
AGE*S2	Age and work pressure factor	Depression
SEX*S2	Sex and work pressure factor	Anxiety
SEX*S2	Sex and work pressure factor	Extreme fatigue
EWT*LUM	Type of eye wear and luminance around VDT workstation	Extreme fatigue
TASK*LPJ	Type of VDT task and length of time at present job	Extreme fatigue
TOC*POSIT	Time of using computer continuously and layout of screen and keyboard	Ocular discomfort
P1*POSIT	Upper body posture and layout of screen and keyboard	Upper body symptoms (wrists, upper back, neck and shoulders)
AGE*EWT	Age and type of eye wear	Blurred vision, ringing ears and stomach ache

psychological stress and "other physical symptoms" which were found to be stress related. Table 7.1 lists the interactions found in this study and their effects. It is noticed that only the interaction between two variables were examined.

7.4 SUBJECTIVE AND OBJECTIVE MEASUREMENTS

As discussed in Chapter 3, research with VDTs has been designed to develop and test hypotheses about effects of VDTs on the operators. Tests of these hypotheses have been made in two ways: survey and experiments. Survey approach has been used

Table 7.2 Summary of subjective and objective measurements

	Objective Measurements	Subjective Measurements	Canonical Correlation
Screen glare	1. Presence of screen glare 2. Proportion of display affected 3. Degree of image visibility loss	Degree of screen glare	0.52**
Screen position	1. Screen position 2. Screen height	1. Comfort with screen position 2. Comfort with screen height	0.23
Keyboard position	1. Keyboard position 2. Keyboard height	1. Comfort with keyboard position 2. Comfort with keyboard height	0.43**
Chair comfort	1. Difference between chair height and popliteal height 2. Presence of arm rests	1. Comfort with chair back rest 2. Comfort with chair seat pan 3. Comfort with chair height	0.32

extensively in many past studies of investigating the incidents of the health complaints and related risk factors (Laubli et al., 1983; Lim and Carayon, 1993; Lu et al., 1993a and 1993b; Sauter, 1984). However, it has the disadvantage of being unable to fully control competing causes of effects by randomization. It has been criticized for it's subjective measurements (National Research Council, 1983; Schleifer et al., 1990). The experiment approach has its advantage of being able to control the causal variable(s). However, the experiment environment may be too artificial to generalize to real people in real jobs in some circumstances. This study used the survey approach because that the variables investigated cannot be controlled by the experiment in laboratory conditions. Considering the limitations of the survey approach, this study carefully designed the survey by controlling the survey sites and subjects' experience with their job and using both subjective and objective measurements.

The subjective measures used in this study were subjective reports of health complaints and subjective evaluations of the work place environment by using a careful designed questionnaire. The objective measures used in this study were the measurements of workstation and lighting conditions and posture analysis. To examine the relationship between subjective and objective measurements of workstation and physical work environment, canonical correlation analysis was used. It is found that subjective and objective measurements are significantly correlated. However, they should not be substitute with each other because the variance that can be explained by the other side of measurement is low. This finding is important because some researcher tried to objectively assess glare variables and failed to have any apparent influence on visual system strain (Schleifer et al., 1990). Table 7.2 summaries the subjective and objective measures of workstation and lighting conditions used in this study. It is noticed that some relationships between subjective and objective measures are not significant. This may result from the variables chosen for the measurement.

Another objective measurement used by this research was the postural analysis. This approach is simple and was found to be feasible because reasonable relationships were found between the postural measurement and other variables. The integration of subjective and objective measurements in this study is summarized in Figure 7.1.

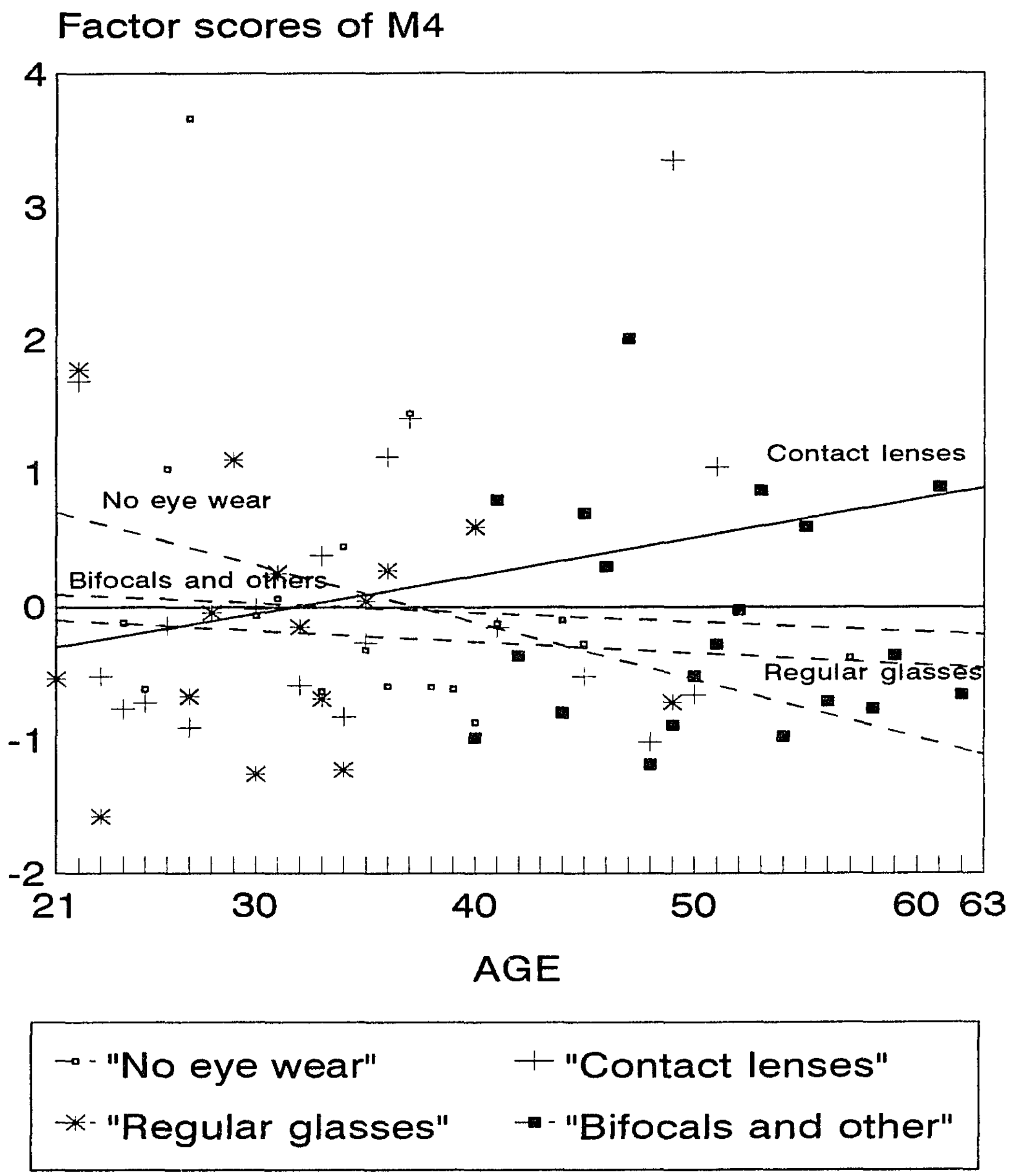


Figure 7.1 Integration of subjective and objective measurements

CHAPTER 8

SUMMARY AND CONCLUSIONS

A literature search shows there is increased concern about the possible "adverse health effects" caused by VDT work and its environment. The prevalence of musculoskeletal disorders and visual fatigue has been recognized; and the contribution of ergonomics factors and environment to visual and musculoskeletal complaints in VDT work is widely identified. However, the interacting relationships between the physical discomfort and possible risk factors remain undefined. There has been little research to defined the interrelationships among these risk factors and to rank their relative importance. The whole picture of variables affecting the VDT workstation system has not been made clear.

The objectives of this research were to determine the most important risk factors in VDT workstation system associated with physical symptoms and to investigate the interrelationship among the risk factors.

8.1 RESEARCH PROCEDURE AND MAJOR RESULTS

This research consisted of the following four stages:

STAGE 1:

Research model development. A conceptual model was developed to present the interrelationship between the basic components in a VDT workstation system and their possible health effects. A research model is then proposed to show the hypothesized relationships among the following categories of variables: demographics, tasks, workstation design, work environment, psychosocial factors, awkward work posture, psychological stress, musculoskeletal symptoms, visual symptoms and general physical symptoms. This study investigated the interrelationship among the above ten categories of variables comprehensively.

STAGE 2:

Methodology development. In order to evaluate the workstation system comprehensively, a method which consisted of a questionnaire, measurement and checklist, and posture analysis was developed. A questionnaire was designed for collecting subjective reports of health symptoms and evaluation of workstation and work environment. A checklist and measurement sheet were designed for collecting data of workstation dimensions, lighting conditions, and anthropometry. A posture analysis method was also developed for evaluating operators' work postures. By using this posture analysis method, the body is divided into the following six parts: head/neck, trunk, upper arms, lower arms, wrists, and legs and feet. Standard postures for each body part are defined and a risk score is assigned to each standard posture. These body parts are numbered so that the number one (1) is given to the working posture or the range of movement where the risk factors present are minimal. Higher numbers are allocated to parts of the working posture or movement range with more extreme posture indicating presence of risk factors causing load on the structures of the body parts.

STAGE 3:

Field study. A field study was conducted among daily computer users at two different sites, a local hospital and Louisiana State University. This field study consisted of three parts, a questionnaire survey, measurements, and video recording of operators' work posture. Ninety-three subjects participated in the study. They were all daily computer uers and they had been at present job for at least three months.

STAGE 4:

Data analysis. Data was analyzed using both univariate and multivariate approaches. Descriptive data shows that the physical symptoms and the symptoms of psychological stress are prevalent among VDT operators. Over 50% of the operators experienced the following symptoms: tired eyes (86.3), extreme fatigue (81.8%), headache (78%), anxiety (63.7%), neck pain (62.5%), shoulder pain (62%), and tearing eyes (60.2%). The top complaints that operators experienced daily were: tired eyes (21.6), shoulder pain (17.2%), neck pain (13.6%), anxiety (11.4%) and headache (8%). In order to identify the most important variables used for testing the research model, the relationship between objective and subjective evaluation of workstation and environment was investigated. The results show that the objective and subjective measurements were significantly correlated but they should not be substituted for each other. Canonical correlation analysis was applied to investigate the relationship among the ten categories of variables under a multivariate environment. The results show that the three categories of physical symptoms, i.e. musculoskeletal, visual, and general physical symptoms are significantly interrelated and the variables related to the each category of symptoms are different. Musculoskeletal symptoms are related to awkward posture and psychological stress; visual symptoms are related to awkward posture, psychological stress, workstation design, work environment, and psychosocial factors; and the general physical symptoms are related to psychological stress and psychosocial factors.

Multiple regression method was used to determine the most important factors related to the physical symptoms and the effect of interactions among the risk factors. Factor analysis was applied to the physical symptoms to identify the underlying factors. Four factors were identified: ocular discomfort, general musculoskeletal symptoms, upper extremity symptoms, and other physical symptoms. Ocular discomfort is significantly related to screen glare; general musculoskeletal symptoms and other physical symptoms are related to fatigue; and upper extremity discomfort is related to awkward upper body posture. The following interactions among the risk factors are identified to affect the physical symptoms, the period of time of using computer and workstation layout, work posture and workstation layout, and age and type of eye wear. It is found that when the period of time of using computer is various, operators have less complaints about ocular discomfort although the workstation layout is poor. As the time of using computer increases, the complaint about ocular discomfort increases among the VDT operators with both good and bad designed workstation. The complaint of ocular discomfort is more among VDT operators with poor designed workstation than that with good designed workstation. Examination of the interaction between work posture and workstation design found that upper body symptom (symptoms in wrist, shoulder and neck areas) is affected more by poor work posture (extremity posture) as the workstation design becomes worse.

Risk factors associated with awkward posture and psychological stress were also identified. Many interactions were found to affect the work posture and psychological stress, such as, psychosocial factors and demographic variables, workstation design and working posture. The interaction of the layout of screen and keyboard and screen glare is the most important risk factor for awkward work posture. Psychosocial factors are identified to interact with other variables and contribute to psychological stress. It is found that the extremity posture (lower arm, wrist and leg and foot posture) is significantly affected by work pressure factor (psychosocial factor) among female VDT operators ($F=4.066$, $df=1$, $p=0.0482$), the higher the work pressure, the more awkward posture. However, the effect is not significant among male VDT operators. The effect of psychosocial factors on the psychological stress is also more significant among female worker than among male workers.

8.2 CONCLUSIONS

In summary, several conclusions can be drawn from this research:

1. The risk factors contributing to different physical symptoms are different and these factors are inter-related. Screen glare is the most important risk factor contributing to ocular symptoms; fatigue and awkward posture are the most important risk factors to general musculoskeletal symptoms; awkward posture is the most important risk factor to upper body symptoms; and fatigue is the most important factor to other physical symptoms. The risk factors found in this study are summarized in Table 8.1. The risk factors in bold are the most important to the health symptoms.

2. Psychosocial factors should not be ignored when examining the workstation design factors and work environment. Psychosocial factors interact with other variables and contribute to work posture psychological stress. The effect is more significant among female workers than among male workers.

3. Workstation design significantly affects working posture which in turn contributes to physical symptoms.

4. Interactions exist among the risk factors not only within but also between the seven categories of risk factors.

5. Both subjective and objective measures should be used in investigating risk factors in the VDT system.

8.3 THE IMPACT AND CONTRIBUTIONS OF THIS RESEARCH

With the increased use of computers in offices, VDT operators' health and well-being become an important issue to management, health and safety professionals. The objective is to provide an environment which increases productivity and work efficiency

Table 8.1 Summary of risk factors in VDT workstation systems

Physical Symptoms	Risk Factors
Ocular discomfort • Tearing eyes • Dry eyes • Burning eyes • Tired eyes	• Workstation design: **-Screen glare** -Layout of screen and keyboard -Time of using computer continuously • Awkward posture • Psychosocial factor: -Job satisfaction • Work environment: -Discomfort with illumination -Luminance around workstation
General musculoskeletal symptoms • Lower back • Headache • Neck • Shoulders	• **Extreme fatigue** • Awkward posture • Age • Time of using computer continuously
Upper body symptoms • Wrists • Upper back • Neck • Shoulders	• **Awkward posture** • Depression • VDT work history • Workstation design
Other physical symptoms • Ringing ears • Stomach discomfort • Blurred vision	• **Extreme fatigue** • Total time of using computer /day • Age • Type of eye wear
Awkward Work Posture • Upper body posture • Extremity posture	• **Workstation design** • Sex • Work pressure • Illumination level • Comfort with work space • Working hours/day • Time of using computer continuously
Psychological Stress • Depression • Anxiety • Extreme fatigue	• **Psychosocial factors:** -Job satisfaction -Work pressure factor • Awkward work posture • Workstation design • Task: -Time of using computer continuously -Type of VDT tasks • Demographics: -Sex -Age -Type of eye wear -Length of time at present job • Work environment: -Luminance around workstation -Comfort with work space

and reduces operator health complaints and turn over. To achieve this purpose, identifying the risk factors in the VDT workstation system is very important for the development of prevention strategies. Although numerous studies have been performed for the investigation of health complaints and their related risk factors, and many risk factors have been identified, the interacting relationship among the risk factors has not been made clear. This study has moved ergonomics research forward by examining the inter-relationship of the risk factors more comprehensively. Future research can be developed based on the conceptual model and the methodology developed in this study.

This study also shows that both the physical and psychosocial environments need to be considered to optimize operators' health in a VDT workstation system. The most important factors identified and the interactions among the risk factors described in this research will be very useful in further effort.

In summary, the contributions of this research to the investigation of risk factors in VDT systems are as follows:

1. Development of a conceptual model which presents the interaction of basic components in a VDT workstation system.

2. Development of a posture analysis method which can be used to rate the risk associated with the working posture at VDT workstation.

3. Development of a method which integrated both subjective measures (questionnaire) and objective measures (workstation measurement and posture analysis) for the investigation of risk factors in the VDT workstation system.

4. Classification of the physical symptoms into four (4) categories, i.e. ocular symptoms, general musculoskeletal symptoms, upper body symptoms, and other physical symptoms.

5. Comprehensive examination of the effect of both the physical and psychosocial environment and their interactions to the physical symptoms, awkward work posture and psychological stress.

The implication of this research is that both physical and social environment need to be evaluated and the inter-relationships between the components in a VDT workstation system need to be understood in order to determine the risk factors to the physical symptoms.

CHAPTER 9

RECOMMENDATIONS FOR FUTURE WORK

The goal of identifying risk factors in VDT workstation systems is to help prevent injury among VDT operators. Figure 9.1 represents a process for achieving this goal. As a first step, the prevalence of injury and related cost need to be identified; then the risk factors for these physical symptoms need to be determined. After identifying the most important risk factors, the process which identifies how these risk factors can lead to injury need to be researched and the cutoff scores need to be determined. Finally, prevention strategies can be developed based on the above mentioned quantitative results.

Many studies have been conducted to identify the prevalence of the physical symptoms. Many studies have also investigated the related risk factors associated with the physical symptoms. This study investigated comprehensively the risk factors associated with physical symptoms, work posture and psychological stress by examining both the physical and social environment. As a result of the study, the relationship among the many complex musculoskeletal, visual, psychological and environmental variables for the VDT user are understood better.

Based on this study, the followings are recommended for further investigation:

1. Validation of the conceptual and research models developed in this study. Further field and laboratory studies are needed to validate the relationships presented in this research. The variables in each category of the system components need to be

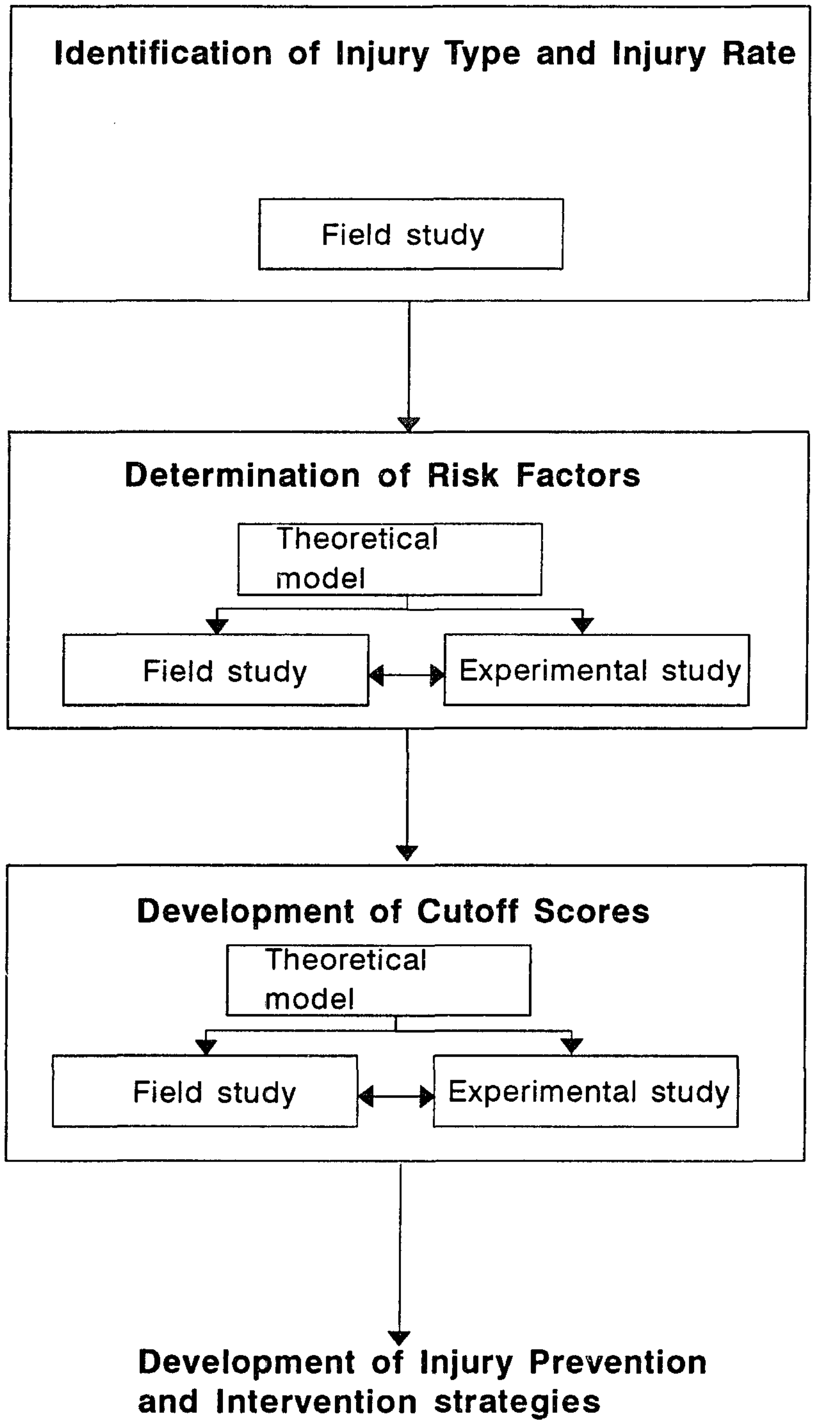


Figure 9.1 Proposed process for the research in VDT workstation systems

further defined and examined. Future experimental studies should be developed for validating the relationship among the components of the physical work environment, which include workstation design, lighting conditions and other environmental variables and their possible effects.

2. Interactions among risk factors. Much work has been done to identify the risk factors and examine their effects on the VDT operators health in the literature. However, very few studies have identified and examined the interactions of the risk factors. Since the variables in the VDT systems do not exist independently, their effects should also be examined simultaneously, especially the interacting relationship between the physical and social environment.

3. Understanding the injury process. The process of the exposure to the risk factors and the resulted injury need to be researched and understood. A quantitative description of all the human components are of all the risk factors is not yet possible. However, the process of the exposure to some risk factors, such as repetition and duration, and potential injuries to muscles, tendons, and nerves should be studied and quantified.

4. Development of reasonable injury prevention cutoff scores. Once we identify the risk factors and understand the potential injury process, it is imperative to develop the reasonable injury prevention cutoff score for work duration and musculoskeletal stress. Intervention and prevention strategies can therefore be developed.

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APPENDIX A

VARIABLES STUDIED IN THE QUESTIONNAIRE

DEMOGRAPHICS/INDIVIDUAL CHARACTERISTICS

SEX Gender
AGE Age
JBT Job title
LPJ Length of present job_______ months
VDT Computer experience _______ months
TYS Typing speed
EWT Eye wear type
EEF Eye exam frequency
HAB Sitting habits
EXB Exercises during breaks?
EXS Exercises?

TASKS

WHD Working hours/day
TAS Major tasks
TOC Length of time using computer continuously
TOU Total time of using computer
TOM Percentage of using mouse

PSYCHOSOCIAL FACTORS

FTP Times of feeling time pressure
FSW Surges in workload
JCS Satisfy job challenge?
JRS Job responsibility?
JSA Sense of accomplishment?
SSP Supervisor support?
SFB Supervisor feedback?
WIT Interaction at work?

COMPUTER AND SYSTEMS

CST Computer type
CSS Type of software

WORKSTATION ERGONOMICS

-SUBJECTIVE EVALUATIONS:

SCG Screen glare
SCP Comfort with the screen position
KBP Comfort with the position of keyboard
CHT Comfort with the height of chair
CBR Comfort with the back rest
CSP Comfort with the seat pan

-OBJECTIVE EVALUATIONS

SGL Screen glare
SGP Proportion of the display affected by screen reflections
SGI Degree of image visibility loss due to screen glare
SPT Screen position
KBP Position of keyboard
ARM Presence of arm rest?
CHD Copy holder?
WRT Use of wrist rest?

-MEASUREMENTS

MVD Viewing distance from screen
MVS Viewing distance from source document
MVH VDT height
MWH Working table height
MSH Seat height

-ANTHROPOMETRY MEASUREMENTS

AHT Height
AEH Eye height
ABH Elbow height
APH Popliteal height

WORK ENVIRONMENT

-SUBJECTIVE EVALUATIONS:

ICR Comfort with the illuminance level
NLR Comfort with the noise level
THR Comfort with environment
WSR Comfort with the working space
WAR Comfort with the working area

-OBJECTIVE EALUATION/MEASUREMENTS

MVL Display luminance
MKL Keyboard luminance
MDL Document luminance
MFL Visual foreground luminance, 30° left
MFR Visual foreground luminance, 30° right
MFB Visual foreground luminance, behind
MSI Illuminance at screen
MKI Illuminance at keyboard
MDI Illuminance at source document

POSTURE ANALYSIS VARIABLES

DOMINANT POSTURE

PHN Deviation of head and neck from the trunk:
PTK Torso/trunk
PSD Shoulders
PBS Back supported?
PEA Elbow angle between forearm and upper arm:
PWT Wrist posture
PFA Forearm posture

DYNAMIC POSTURE

PHV Head movement direction
PTV Trunk movement direction
PWT Wrists support while typing?
PWB Whole body movement

MUSCULOSKELETAL SYMPTOMS

NCE Neck
SHE Shoulders
UBE Upper back
LBE Lower back
ELE Elebows
WHE Wrists

VISUAL SYMPTOMS

TIE Tearing/itching eyes
DRE Dry eyes
BVE Blurred vision
BEE Burning eyes?
TRE Tired eyes?

GENERAL PSYSICAL SYMPTOMS

HDE Headache?
ERE Ringing ears?
SDE Stomach discomfort

PSYCHOLOGICAL STRESS

UFE Extreme fatigue?
ANX Anxiety
DEP Depression

APPENDIX B

QUESTIONNAIRE

VDT WORKSTATION SURVEY

A Questionnaire Presented to Computer Users

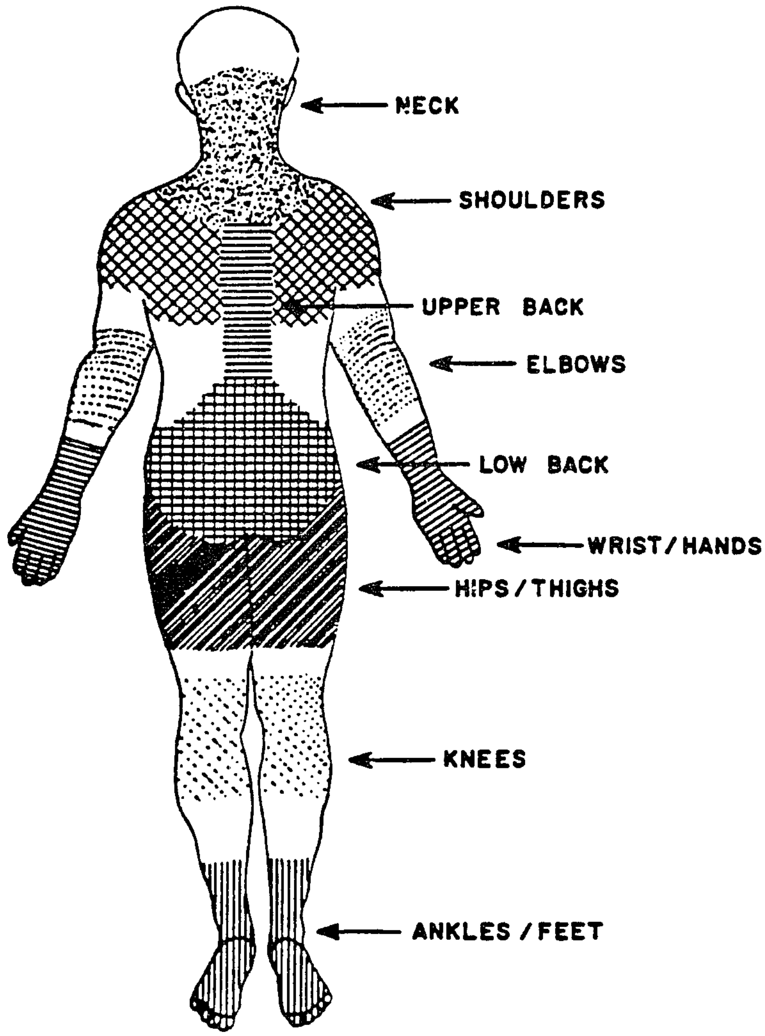
OBJECTIVE:

The objective of this survey is to obtain subjective opinion of the health problems and evaluation of the workstation system. The questions are divided into three parts: (I) background information, (II) possible health symptoms, and (III) perceived comfort of the computer, workstation and environment. All information obtained from each individual will be kept confidential. A general summary of findings will be provided after the study.

How To Answer the Questionnaire:

Please mark your answer for each question by putting an X in the appropriate box(s). You may have more than one answer for some of the questions. In this case, you should select all the answers which apply to you. It is most important that you answer all questions to the best of your ability.

Thank you for participating. The time and effort you invest are greatly appreciated.



Body map used in the questionnaire
(Source: Chaffin and Andersson, 1991, reprinted by permission of John Wiley & Sons, Inc.)

I. Background Information

Sex: ☐ female ☐ male	Age:
Vison	
Indicate the type of eye wear you use at work: 1 ☐ None 2 ☐ Contact lenses 3 ☐ Regular glasses 4 ☐ Bifocals 5 ☐ Trifocals 6 ☐ Other (please specify)______	How often do you have your eyes examined? 1 ☐ No periodic eye examination 2 ☐ Every 3 or 6 months 3 ☐ Annually 4 ☐ Every two years 5 ☐ Every three years or more
If you use any type of eye wear at work, is it prescribed specially for computer use? 1 ☐ Yes 2 ☐ No	When was the last time you had your eyes examined? 1 ☐ Less than a year ago 2 ☐ Over a year ago
Work experiences/Tasks	
Job title:	Length of time on present job: ______(yrs)______ (mths) Computer work history: _____(yrs)_______ (mths) Working hrs/day: Total working hrs/week:
What is your approximate typing speed? 1 ☐ less than 40 wpm 2 ☐ 40-50 wpm 3 ☐ 50-60 wpm 4 ☐ above 60 wpm	Do you use a mouse? ☐ No ☐ Yes If YES, how often? 1 ☐ ≤ 25% of time 2 ☐ 25-50% of time 3 ☐ 50-75% of time 4 ☐ 75-100% of time
Please indicate the major task you perform with computer: 1 ☐ Entering numerical data 2 ☐ Typing letters/memos/reports 3 ☐ Interactive work/retrieving information 4 ☐ Programming 5 ☐ Drawing/CAD	How much time a day do you actively use the computer? 1 ☐ 0-1 hour 2 ☐ 1-2 hours 3 ☐ 2-4 hours 4 ☐ 4-6 hours 5 ☐ more than 6 hours 6 ☐ It varies greatly
When you use a computer for your major tasks, how long do you use it continuously? 1 ☐ About 5 min or less 2 ☐ About 10 min 3 ☐ About 10-30 min 4 ☐ About 30-60 min 5 ☐ About 1-2 hours 6 ☐ About 2-4 hours 7 ☐ The period of time varies greatly	Is there any production standard for your computer tasks (i.e. have to type certain pages to get the pay)? ☐ Yes ☐ No If YES, what do you think of the standard? 1 ☐ Too tight 2 ☐ A little too tight 3 ☐ Just right 4 ☐ A little loose 5 ☐ Too loose

Do you feel surges in workload? 1 ☐ Never 2 ☐ Less than once a week 3 ☐ Once a week 2 ☐ Several times a week 3 ☐ Daily	Do you feel time pressure in completing your computer tasks? 1 ☐ Never 2 ☐ Less than once a week 3 ☐ Once a week 4 ☐ Several times a week 5 ☐ Daily

Habits/Exercises	
When performing typing tasks, where do you usually place the hard copy? 1 ☐ Clip it on a copy stand 2 ☐ Place it flat on desk 3 ☐ Hold it by one hand	When typing, you usually have your palms and wrists supported by: 1 ☐ The table 2 ☐ A wrist rest/the edge of keyboard drawer 3 ☐ Nothing
When you need more than 1 hour to do a job with a computer, how do you take breaks? 1 ☐ No breaks till I finish the work 2 ☐ Some short breaks to alternate the work	Do you do some simple exercises during the breaks? 1 ☐ Never 2 ☐ Sometimes 3 ☐ Frequently
Do you have the following habits while sitting? 1 ☐ Crossing the legs 2 ☐ Putting the feet on wheels/supports of chair 3 ☐ Sitting at the front edge of the chair 4 ☐ Using footrest 5 ☐ None of above	Do you do any type of exercise which lasts 20 min or longer (walk, run, aerobics, etc.)? 1 ☐ Never 2 ☐ Less than once a week 3 ☐ Once a week 4 ☐ Several days a week 5 ☐ Daily

Please circle the response that indicate your level of agreement with various aspects of this job
1. The amount of challenge in my job is: Very dissatisfying 1 2 3 4 5 6 Very satisfying
2. I feel a great deal of personal responsibility for the job I do. Strongly disagree 1 2 3 4 5 6 Strongly agree
3. I feel a great sense of accomplishment when I do my job well. Strongly disagree 1 2 3 4 5 6 Strongly agree
4. The amount of support I received from my supervisor is: Very dissatisfying 1 2 3 4 5 6 Very satisfying
5. My supervisor often gives me feedback regarding my performance. Strongly disagree 1 2 3 4 5 6 Strongly agree
6. I always have chance to get to know or talk to other people while working. Strongly disagree 1 2 3 4 5 6 Strongly agree

II. Possible Health Symptoms

Please state the area(s) you have had stiffness, ache, pain, numbness, or discomfort at any time.	If you answered YES to the left column, please answer the following questions:	
Neck: ☐ No ☐ Yes	When did you start having this symptom? _________ years/months ago Have you ever hurt your neck in an accident? ☐ No ☐ Yes	Since you got this problem, how often does it bother you? 1 ☐ Less than once a week 2 ☐ Once a week 3 ☐ Several times a week 4 ☐ Daily
Shoulders: ☐ No ☐ Yes	When did you start having this symptom? _________ years/months ago Have you ever hurt your shoulders in an accident? ☐ No ☐ Yes	Since you got this problem, how often does it bother you? 1 ☐ Less than once a week 2 ☐ Once a week 3 ☐ Several times a week 4 ☐ Daily
Upper back: ☐ No ☐ Yes	Have you ever hurt your upper back in an accident? ☐ No ☐ Yes Have you ever hurt your lower back in an accident? ☐ No ☐ Yes	Since you got this problem, how often does it bother you? 1 ☐ Less than once a week 2 ☐ Once a week 3 ☐ Several times a week 4 ☐ Daily
Lower back: ☐ No ☐ Yes	When did you start having this symptom? _________ years/months ago Have you ever hurt your lower back in an accident? ☐ No ☐ Yes	Since you got this problem, how often does it bother you? 1 ☐ Less than once a week 2 ☐ Once a week 3 ☐ Several times a week 4 ☐ Daily
Elbows: ☐ No ☐ Yes	When did you start having this symptom? _________ years/months ago Have you ever hurt your elbows in an accident? ☐ No ☐ Yes	Since you got this problem, how often does it bother you? 1 ☐ Less than once a week 2 ☐ Once a week 3 ☐ Several times a week 4 ☐ Daily
Wrists/hands: ☐ No ☐ Yes	When did you start having this symptom? _________ years/months ago Have you ever hurt your wrists/ hands in an accident? ☐ No ☐ Yes	Since you got this problem, how often does it bother you? 1 ☐ Less than once a week 2 ☐ Once a week 3 ☐ Several times a week 4 ☐ Daily

Hips/thighs: ☐ No ☐ Yes	When did you start having this symptom? _________ years/months ago Have you ever hurt your hips/thighs in an accident? ☐ No ☐ Yes	Since you got this problem, how often does it bother you? 1 ☐ Less than once a week 2 ☐ Once a week 3 ☐ Several times a week 4 ☐ Daily
Knees: ☐ No ☐ Yes	When did you start having this symptom? _________ years/months ago Have you ever hurt your knees in an accident? ☐ No ☐ Yes	Since you got this problem, how often does it bother you? 1 ☐ Less than once a week 2 ☐ Once a week 3 ☐ Several times a week 4 ☐ Daily
Ankles/feet: ☐ No ☐ Yes	When did you start having this symptom? _________ years/months ago Have you ever hurt your ankles/feet in an accident? ☐ No ☐ Yes	Since you got this problem, how often does it bother you? 1 ☐ Less than once a week 2 ☐ Once a week 3 ☐ Several times a week 4 ☐ Daily

Please indicate the frequency/intensity of the following symptoms if you have any during work	
Tearing/itching eyes? 1 ☐ Never 2 ☐ Less than once a week 3 ☐ Once a week 4 ☐ Several times a week 5 ☐ Daily	Burning eyes? 1 ☐ Never 2 ☐ Less than once a week 3 ☐ Once a week 4 ☐ Several times a week 5 ☐ Daily
Dry eyes? 1 ☐ Never 2 ☐ Less than once a week 3 ☐ Once a week 4 ☐ Several times a week 5 ☐ Daily	Tired eyes? 1 ☐ Never 2 ☐ Less than once a week 3 ☐ Once a week 4 ☐ Several times a week 5 ☐ Daily
Blurred vision/double vision? 1 ☐ Never 2 ☐ Less than once a week 3 ☐ Once a week 4 ☐ Several times a week 5 ☐ Daily	Acquiring new glasses because of deteriorating vision? 1 ☐ Never 2 ☐ Every 6 months 3 ☐ Every year 4 ☐ Every 18 months 5 ☐ Every 2 years or over

Please indicate the frequency of the following symptoms if you have any during work	
Extreme fatigue? 1 ☐ Never 2 ☐ Less than once a week 3 ☐ Once a week 4 ☐ Several times a week 5 ☐ Daily	Headaches or dizziness? 1 ☐ Never 2 ☐ Less than once a week 3 ☐ Once a week 4 ☐ Several times a week 5 ☐ Daily
Ringing ears? 1 ☐ Never 2 ☐ Less than once a week 3 ☐ Once a week 4 ☐ Several times a week 5 ☐ Daily	Stomach discomfort? 1 ☐ Never 2 ☐ Less than once a week 3 ☐ Once a week 4 ☐ Several times a week 5 ☐ Daily
Anxiety, because of the work, computer, workstation, and/or environment? 1 ☐ Never 2 ☐ Less than once a week 3 ☐ Once a week 4 ☐ Several times a week 5 ☐ Daily	Depression, because of the work, computer, workstation, and/or environment? 1 ☐ Never 2 ☐ Less than once a week 3 ☐ Once a week 4 ☐ Several times a week 5 ☐ Daily

III. Computer, Workstation, and Work Environment

Screen	
1. Please rate the glare on the screen: 1 ☐ None 2 ☐ Slight 3 ☐ Moderate 4 ☐ Severe	2. Please rate the legibility of screen characters: 1 ☐ Excellent 2 ☐ Good 3 ☐ Fair 4 ☐ Poor
3. Please rate the readability of text on the screen: 1 ☐ Excellent 2 ☐ Good 3 ☐ Fair 4 ☐ Poor	4. Please rate the comfort with the screen size: 1 ☐ Comfortable 2 ☐ Slightly uncomfortable 3 ☐ Moderately uncomfortable 4 ☐ Uncomfortable
5. Please rate the comfort with the position of screen monitor: 1 ☐ Comfortable 2 ☐ Slightly uncomfortable 3 ☐ Moderately uncomfortable 4 ☐ Uncomfortable	6. Please rate the height of the screen: 1 ☐ Too high 2 ☐ A little high 3 ☐ Just right 4 ☐ A little low 5 ☐ Too low

Keyboard	
1. Please rate the comfort with the position of keyboard: 1 ☐ Comfortable 2 ☐ Slightly uncomfortable 3 ☐ Moderately uncomfortable 4 ☐ Uncomfortable	2. Please rate the height of the keyboard: 1 ☐ Too high 2 ☐ A little high 3 ☐ Just right 4 ☐ A little low 5 ☐ Too low

Chair	
1. Please rate the height of chair that you use: 1 ☐ Too high 2 ☐ A little high 3 ☐ Just right 4 ☐ A little low 5 ☐ Too low	2. If your chair is too high or too low, indicate the reason(s): 1 ☐ The chair is not adjustable 2 ☐ Even I adjust the chair, it still does not fit me 3 ☐ I have to match the height of working surface 4 ☐ Other (specify)
3. Please rate the back rest of the chair: 1 ☐ Comfortable 2 ☐ Slightly uncomfortable 3 ☐ Moderately uncomfortable 4 ☐ Uncomfortable	4. Please rate the seat pan of your chair: 1 ☐ Comfortable 2 ☐ Slightly uncomfortable 3 ☐ Moderately uncomfortable 4 ☐ Uncomfortable

Environment	
1. Please rate the illuminance of the working area: 1 ☐ Too bright 2 ☐ A little too bright 3 ☐ Just right 4 ☐ A little too dim 5 ☐ Too dim	2. Please rate the comfort level of the illumination: 1 ☐ Comfortable 2 ☐ Slightly uncomfortable 3 ☐ Moderately uncomfortable 4 ☐ Uncomfortable
3. Please rate the noise level of your working area: 1 ☐ No noise at all 2 ☐ Slightly noisy 3 ☐ Moderately noisy 4 ☐ Too noisy	4. Please rate the temperature, humidity, and ventilation conditions around your workstation: 1 ☐ Comfortable 2 ☐ Slightly uncomfortable 3 ☐ Moderately uncomfortable 4 ☐ Uncomfortable
5. What do you think of your working space? 1 ☐ Too cramped 2 ☐ A little too cramped 3 ☐ Just right 4 ☐ A little too big 5 ☐ Too big	6. What do you think of your working area? 1 ☐ Too open (no privacy at all) 2 ☐ A little too open 3 ☐ Just right 4 ☐ A little too closed 5 ☐ Too closed (no interaction with other people)

APPENDIX C

MEASUREMENT AND CHECKLIST

VDT WORKSTATION SURVEY

Measurement

No.	MEASURED ITEM	MEASUREMENT			UNITS	INSTRUMENT
1	Screen size (diagonal)				inches	Tape measure
2	Viewing distance from screen				cm	Tape measure
3	Viewing distance from source document				cm	Tape measure
4	VDT height (center of screen)				cm	Anthropometry set
5	Working table height				cm	Anthropometry set
6	Keyboard height (home row)				cm	Anthropometry set
7	Seat height				cm	Anthropometry set
8	Display luminance				footlamberts	Triple range 214 light meter
9	Keyboard luminance				footlamberts	Triple range 214 light meter
10	Document luminance				footlamberts	Triple range 214 light meter
11	Visual foreground luminance: a) 30° left of the VDT b) 30° right of the VDT c) directly behind the VDT				footcandles	Triple range 214 light meter
12	Illuminance at screen				footcandles	Triple range 214 light meter
13	Illuminance at keyboard				footcandles	Triple range 214 light meter
14	Illuminance at source document				footcandles	Triple range 214 light meter

No.	ANTHROPOMETRY MEASUREMENT	DATA
1	Height (cm)	
2	Eye height while sitting (cm)	
3	Elbow height while sitting (cm)	
4	Popliteal height (cm)	

VDT WORKSTATION SURVEY

Checklist

COMPUTER SYSTEM	
Type of computer: 1 ☐ IBM pc or compatible 2 ☐ Macintosh 3 ☐ Mainframe terminal 4 ☐ Workstation 5 ☐ Other	Computer model/speed:
	Type of software

SCREEN and	GLARE
1. Screen position: ☐ front ☐ side 2. Screen glare: ☐ Yes ☐ No	3. Anti-glare screen: ☐ Yes ☐ No If the answer is NO for question 2, ignore question 4 - 8.
4. Sources of glare: ☐ window ☐ overhead lighting ☐ task lamp	5.Proportion of the display affected by screen glare: ☐ 0-25% ☐ 26-50% ☐ 50-75% ☐ 76-100%
6. Degree of image visibility loss due to screen glare: ☐ None ☐ Low ☐ Medium ☐ High	7. Presence of a window: 1 ☐ None 2 ☐ Yes, at the back of screen 3 ☐ Yes, in front of screen 4 ☐ Yes, at the right or left side.
8. Curtain or blind at the window: ☐ Yes ☐ No	

KEYBOARD, DOCUMENT HOLDER, WRIST REST, and CHAIR	
9. Position of keyboard: ☐ front ☐ side	10. Document holder: ☐ Yes ☐ No If YES, position: ☐ Attach to the screen: ☐ right ☐ left ☐ Place at the side of screen: ☐ right ☐ left
11. Seat adjustability: Arm rest: ☐ Yes ☐ No Height: ☐ Yes ☐ No Seat pan angle: ☐ Yes ☐ No Back rest: ☐ Yes ☐ No	12. Use of back support? ☐ Yes ☐ No 13. Present of wrist rest: ☐ Yes ☐ No 14. Computer table? ☐ Yes ☐ No

APPENDIX D

MEASUREMENT TECHNIQUES

1. MEASUREMENT OF ILLUMINANCE AND LUMINANCE

EQUIPMENT:

General Electric Type 214 Light Meter

ILLUMINANCE

To determine the level of illumination incident on a surface, set the meter on the surface or hold it with the cover place parallel to the surface. Avoid standing in such a way as to block light from reaching the meter, or ro reflect extra light on the meter from light graments.

LUMINANCE

The apparent brightness of diffuse surface may be approximately obtained with the meter. For transmitting surfaces, hold the meter with diffusing plate close to the surface. For reflecting surfaces, hold it a few inches off the surface, and avoid shadowing the area. The footcandle reading obtained in each case is the approximate luminance of the surface in footlamberts.

Reference: General Electric Type 214 light meter manual. Lighting Business Group. Nela Park #4163, Cleveland, OH 44112. (212)266-9002.

2. ANTHROPOMETRY MEASUREMENT

HEIGHT:

Description: The vertical distance between the floor and top of the head.

Body position: standing.

EYE HEIGHT:

Description: The vertical distance between the floor and a corner of an eye.

Body position: Sitting.

ELBOW HEIGHT:

Description: The vertical distance between the floor and the bottom of the elbow bent 90 degrees.

Body position: Sitting.

POPLITEAL HEIGHT:

Description: The vertical distance between the floor and the underside of the knee of a seated subject.

Body position: Sitting; knees flexed 90 degrees.

Reference: Selection of dimensions for an anthropometric data base. United States Army Natick Research, Development and Research Center. Naitck, Massachusetts 01760-5000. 1986.

3. WORKSTATION MEASUREMENT

VIEWING DISTANCE FROM SCREEN
The distance from eye to the center of screen.

VIEW DISTANCE FROM SOURCE DOCUMENT
The distance from eye to the center of document.

VDT HEIGHT
The vertical distance from the floor to the center of screen.

WORKING TABLE HEIGHT
The vertical distance from the floor to the top of working surface.

KEYBOARD HEIGHT
The vertical distance from the floor to the top of home row of the keyboard.

SEAT HEIGHT
The vertical distance from the floor to the seating surface without a seated person.

APPENDIX E

POSTURE ANALYSIS WORK SHEET

POSTURE ANALYSIS WORK SHEET
VDT Workstation Survey

NO.	VARIABLE	BODY PARTS	SCORE RANGE	OTHER SCORES	FINAL SCORE FOR BODY PARTS
1	PHN	Head/ neck	1. 10° extension to 20° flexion; 2. 20° or more flexion; 3. 10° or more extension.	Posture or movement is twisted? 0. No 1. Yes	
2	PTK	Torso/ trunk	1. 20° extension to 20° flexion; 2. 20° or more flexion;	Movement is twisted? 0. No 1. Yes	
				Movements have been observed? 0. Yes 1. No	
				Lower back is supported? 0. Yes 1. No	
3	PUA	Upper arms	1. 0-20° flexion 2. 20-45° flexion 3. 45° or more flexion	Shoulder is elevated? 0. No 1. Yes	
				Upper arm is abducted? 0. No 1. Yes	
				The weight of arm is supported? 0. No -1. Yes	
4	PLA	Lower arms	1. ≈90° flexion 2. 90 - 135° flexion 3. 70 - 90° flexion 4. <70° flexion		
5	PWT	Wrists	1. 0-15° extension 2. 15° or more extension	Wrists rest on the edge of the keyboard or a wrist rest while typing? 0. No 1. Yes	
6	PLF	Legs /feet	Legs/feet are well supported? 1. Yes 2. No		

VITA

Hongzheng Lu, female, was born in Beinging, the People's Republic of China, on July 26, 1960. She enrolled in the Department of Automation at China Textile University in Shanghai in September 1978 and received a Bachelor's degree in Electrical Engineering in July 1982. She worked as an electrical engineer from 1982 to 1983 in a textile plant. After receiving a Master's degree in Industrial Automation from the same university in April 1986, she worked as an instructor and researcher in the Department of Mechanical Engineering of China Textile University from 1986 to 1989. In August 1989, she enrolled in the Department of Industrial and Manufacturing Systems Engineering at Louisiana State University as a graduate student in an interdisciplinary Ph.D. program in Engineering Science with concentration on ergonomics and minors in computer science and manufacturing systems. She received a Maters's degree in Engineering Science from Louisiana State University in December 1992.

She is a student member of Ergonomics society, Human Factors and Ergonomics society, and Institute of Industrial Engineering. She is also a member of Phi Kappa Phi, a national honor society.

DOCTORAL EXAMINATION AND DISSERTATION REPORT

Candidate: Hongzheng Lu

Major Field: Engineering Science

Title of Dissertation: Modeling of VDT Workstation System Risk Factors

Approved:

____
Major Professor and Chairman

____
Dean of the Graduate School

EXAMINING COMMITTEE:

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Date of Examination:

March 10, 1994